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UTILITY  
PATENT APPLICATION  
TRANSMITTAL

Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.

865 4499

First Named Inventor or Application Identifier

RYUJI NURISHI

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J0921 U.S. PTO  
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## APPLICATION ELEMENTS

MPEP chapter 600 concerning utility patent application contents.

## ADDRESS TO:

Commissioner for Patents  
Box Patent Application  
Washington, DC 20231

1. ☒ Fee Transmittal Form  
(Submit an original, and a duplicate for fee processing)
2. ☐ Applicant claims small entity status.  
See 37 CFR 1.27.
3. ☒ Specification *Total Pages* **49**
4. ☒ Drawing(s) (35 USC 113) *Total Sheets* **16**
5. ☐ Oath or Declaration *Total Pages*
- a. ☐ Newly executed (original or copy)
- b. ☐ Copy from a prior application (37 CFR 1.63(d))  
(for continuation/divisional with Box 17 completed)  
**[Note Box 6 below]**
- i. ☐ **DELETION OF INVENTOR(S)**  
Signed Statement attached deleting  
inventor(s) named in the prior application, see  
37 CFR 1.63(d)(2) and 1.33(b)

6. ☒ Application Data Sheet. See 37 CFR 1.76

7. ☐ CD-ROM or CD-R in duplicate, large table or Computer  
Program (*Appendix*)
8. ☐ Nucleotide and/or Amino Acid Sequence Submission  
(if applicable, all necessary)
- a. ☐ Computer Readable Form (CRF)
- b. Specification Sequence Listing on:
- i. ☐ CD-ROM or CD-R (2 copies); or
- ii. ☐ paper
- c. ☐ Statements verifying identity of above copies

## ACCOMPANYING APPLICATION PARTS

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement ☐ Power of Attorney  
(when there is an assignee)
11. ☐ English Translation Document (if applicable)
12. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☒ Copies of IDS  
Citations
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503)  
(Should be specifically itemized)
15. ☐ Certified Copy of Priority Document(s)  
(if foreign priority is claimed)
16. ☐ Other: \_\_\_\_\_

17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No. \_\_\_\_/\_\_\_\_\_  
Prior application information: Examiner \_\_\_\_\_ Group/Art Unit: \_\_\_\_\_

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

## 18. CORRESPONDENCE ADDRESS

☒ Customer Number or Bar Code Label **05514** (Insert Customer No. or Attach bar code label here) or ☐ Correspondence address below

NAME

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City

State

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Country

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Fax



CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
	TOTAL CLAIMS (37 CFR 1.16(c))	11-20 =	0	X \$ 18.00 =	\$ 0.00
	INDEPENDENT CLAIMS (37 CFR 1.16(b))	1-3 =	0	X \$ 78.00 =	\$ 0.00
	MULTIPLE DEPENDENT CLAIMS (if applicable) (37 CFR 1.16(d))			\$260.00 =	\$ 0.00
				BASIC FEE (37 CFR 1.16(a))	\$ 690.00
			Total of above Calculations =		\$ 690.00
	Reduction by 50% for filing by small entity (Note 37 CFR 1.9, 1.27, 1.28).				
	TOTAL =				\$ 690.00

19. Small entity status

- a. ☐ A small entity statement is enclosed
- b. ☐ A small entity statement was filed in the prior nonprovisional application and such status is still proper and desired.
- c. ☐ Is no longer claimed.

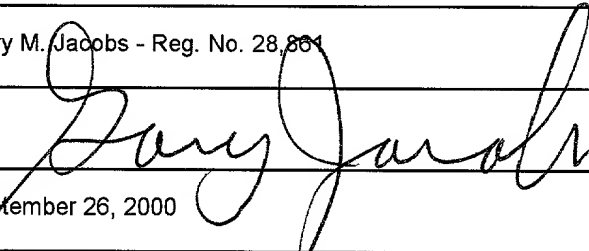
20. ☒ A check in the amount of \$ 690.00 to cover the filing fee is enclosed.

21. ☐ A check in the amount of \$ \_\_\_\_\_ to cover the recordal fee is enclosed.

22. The Commissioner is hereby authorized to credit overpayments or charge the following fees to Deposit Account No. 06-1205:

- a. ☒ Fees required under 37 CFR 1.16.
- b. ☐ Fees required under 37 CFR 1.17.
- c. ☐ Fees required under 37 CFR 1.18.

**SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED**

NAME	Gary M. Jacobs - Reg. No. 28,801
SIGNATURE	
DATE	September 26, 2000

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## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to a zoom lens having an image stabilizing function, and, more particularly, to a zoom lens having an image stabilizing function, which is suited for a television camera, a photographic camera, a video camera or the like, and which has high optical performance over the entire range of variable magnification even during an image stabilizing operation in which a lens unit that is a part of the lens system is made to move in a direction perpendicular to the optical axis so as to correct an image shake caused by the vibration of the zoom lens for the purpose of obtaining a stationary image, with the construction of the zoom lens, such as the refractive power arrangement of the whole zoom lens and the arrangement of the moving lens units for the variation of magnification, appropriately set. Further, the present invention relates to a photographing apparatus having such a zoom lens.

### Description of Related Art

Heretofore, for use with a television camera, a photographic camera, a video camera or the like, there has been a demand for a zoom lens having high optical performance while having a large relative aperture and a high variable magnification ratio.

In addition to such a demand, in the case of a

color television camera for broadcasting, in particular, importance is attached to operability and mobility. In response to such a requirement, the usage of a CCD (charge-coupled device) of 2/3 inch or 1/2 inch has become the mainstream for an image pickup device in the color television camera.

Since the CCD has an almost uniform resolution over the entire image pickup range, a zoom lens to be associated with the CCD is also required to have an almost uniform resolution from the center of an image plane to the periphery thereof.

For example, the zoom lens is required to have the various aberrations, such as coma, astigmatism and distortion, corrected well and to have high optical performance over the entire image plane. In addition, the zoom lens is required to have a large relative aperture, a wide angle of view and a high variable magnification ratio while being small in size and light in weight, and moreover to have a long back focal distance for enabling a color separation optical system and a variety of filters to be disposed in front of an image pickup means.

In addition, it has become a large problem to suppress an image shake caused by the vibration of a photographing system which has a long focal length or the vibration of hands holding the photographing system. Accordingly, a demand for an image stabilizing function of preventing an image shake has risen. Under the









unit that is a part of a photographing system to decenter in a direction perpendicular to the optical axis, although there is such an advantage that it is unnecessary to provide a specific optical system used for the image stabilization, a problem arises in that a space is required for the lens unit to be moved and the amount of occurrence of decentering aberration during the image stabilization becomes large.

In the four-unit zoom lens composed of four lens units of positive, negative, positive and positive refractive powers, respectively, in which the image stabilization is performed by moving the front lens subunit of positive refractive power of the fourth lens unit in a direction perpendicular to the optical axis, as proposed in Japanese Laid-Open Patent Application No. Hei 7-92431, the front lens subunit of positive refractive power serving as an image-stabilizing lens unit has a relatively large effective diameter, and, as a result, there is a tendency for the image-stabilizing lens unit to become large and heavy to increase the size of a driving mechanism for the image-stabilizing lens unit.

In the five-unit zoom lens composed of five lens units of positive, negative, positive, negative and positive refractive powers, respectively, in which the image stabilization is performed by moving the fourth lens unit in a direction perpendicular to the optical axis, as proposed in Japanese Laid-Open Patent Application No. Hei 10-90601, since the fourth lens unit

is a lens unit arranged to move in the optical axis direction during the variation of magnification, there is a tendency for a driving control mechanism for the fourth lens unit to become complicated.

#### BRIEF SUMMARY OF THE INVENTION

It is an object of the invention to provide a zoom lens having an image stabilizing function suited for the so-called four-unit zoom lens, in which the shaking of a photographed image is corrected by driving a lens unit that is a part of the zoom lens to decenter in a direction perpendicular to the optical axis, and each lens element of the zoom lens is appropriately set to reduce the size of the image-stabilizing lens unit and to correct well the various aberrations and decentering aberration. It is another object of the invention to provide a photographing apparatus having the above zoom lens.

To attain the above objects, in accordance with an aspect of the invention, there is provided a zoom lens comprising, in order from an object side to an image side, a first lens unit of positive refractive power, a second lens unit of negative refractive power arranged to move during variation of magnification, a third lens unit arranged to compensate for shift of an image plane due to the variation of magnification, and a fourth lens unit of positive refractive power, wherein the fourth lens unit has a first lens subunit of negative refractive power,

and an image is displaced by moving the first lens subunit in such a way as to have a component perpendicular to an optical axis of the zoom lens.

In accordance with a preferred aspect of the invention, in the zoom lens, the first lens subunit consists of one positive lens and one negative lens.

In accordance with a preferred aspect of the invention, in the zoom lens, the first lens subunit consists of one positive lens and two negative lenses.

In accordance with a preferred aspect of the invention, in the zoom lens, the fourth lens unit further has a second lens subunit of positive refractive power on the image side of the first lens subunit.

In accordance with a preferred aspect of the invention, in the zoom lens, the third lens unit is of positive refractive power, and the fourth lens unit consists of, in order from the object side to the image side, the first lens subunit of negative refractive power and the second lens subunit of positive refractive power.

In accordance with a preferred aspect of the invention, in the zoom lens, the following condition is satisfied:

$$\alpha' - \alpha < -0.45$$

where  $\alpha$  is a converted inclination angle of incidence on a lens surface on the most object side of the first lens subunit, and  $\alpha'$  is a converted inclination angle of exit from a lens surface on the most image side of the first lens subunit.

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In accordance with a preferred aspect of the invention, in the zoom lens, the following condition is satisfied:

$$v_n(4S) - v_p(4S) > 10$$

where  $v_n(4S)$  is, when the first lens subunit includes only one negative lens, an Abbe number of material of the negative lens included in the first lens subunit or, when the first lens subunit includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in the first lens subunit, and  $v_p(4S)$  is, when the first lens subunit includes only one positive lens, an Abbe number of material of the positive lens included in the first lens subunit or, when the first lens subunit includes a plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in the first lens subunit.

In accordance with a preferred aspect of the invention, in the zoom lens, the following condition is satisfied:

$$v_p(4R) - v_n(4R) > 10$$

where  $v_p(4R)$  is, when the second lens subunit includes only one positive lens, an Abbe number of material of the positive lens included in the second lens subunit or, when the second lens subunit includes a plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in the second lens subunit, and  $v_n(4R)$  is, when the second lens subunit includes only one negative lens, an Abbe number of

material of the negative lens included in the second lens subunit or, when the second lens subunit includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in the second lens subunit.

In accordance with a preferred aspect of the invention, in the zoom lens, an image forming magnification of the second lens unit varies within a range including  $-1\times$  during the variation of magnification, an image forming magnification of the third lens unit varies within a range including  $-1\times$  during the variation of magnification, and the following conditions are satisfied:

$$5 < Z2$$

$$0.15 < Z2 / Z$$

where  $Z2$  is a rate of variation of lateral magnification of the second lens unit, and  $Z$  is a zoom ratio of the zoom lens.

In accordance with a preferred aspect of the invention, in the zoom lens, an extender conversion optical system for varying the focal length of the zoom lens is insertably and detachably disposed in a position on the image side of the first lens subunit.

In accordance with another aspect of the invention, there is provided a photographing apparatus, comprising a zoom lens comprising, in order from an object side to an image side, a first lens unit of positive refractive power, a second lens unit of negative

refractive power, a third lens unit of positive refractive power and a fourth lens unit of positive refractive power, wherein the fourth lens unit has a first lens subunit of negative refractive power, and an image is displaced by moving the first lens subunit in such a way as to have a component perpendicular to an optical axis of the zoom lens, and a casing holding the zoom lens.

These and further objects and features of the invention will become apparent from the following detailed description of preferred embodiments thereof taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 is a sectional view showing the construction of a zoom lens at the wide-angle end according to a numerical example 1 of the invention.

Figs. 2A to 2D are aberration diagrams showing the various aberrations at the wide-angle end in the zoom lens according to the numerical example 1 of the invention.

Figs. 3A to 3D are aberration diagrams showing the various aberrations at the focal length  $f$  of 69.79 mm in the zoom lens according to the numerical example 1 of the invention.

Figs. 4A to 4D are aberration diagrams showing the various aberrations at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 1

of the invention.

Figs. 5A to 5D are aberration diagrams showing the various aberrations at the telephoto end in the zoom lens according to the numerical example 1 of the invention.

Figs. 6A to 6C are aberration diagrams showing lateral aberrations at the wide-angle end in the zoom lens according to the numerical example 1 of the invention.

Figs. 7A to 7C are aberration diagrams showing lateral aberrations at the focal length  $f$  of 69.79 mm in the zoom lens according to the numerical example 1 of the invention.

Figs. 8A to 8C are aberration diagrams showing lateral aberrations at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 1 of the invention.

Figs. 9A to 9C are aberration diagrams showing lateral aberrations at the telephoto end in the zoom lens according to the numerical example 1 of the invention.

Figs. 10A to 10C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 3.00 mm at the wide-angle end in the zoom lens according to the numerical example 1 of the invention.

Figs. 11A to 11C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 3.00 mm at the focal length  $f$  of 69.79 mm in

the zoom lens according to the numerical example 1 of the invention.

Figs. 12A to 12C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 3.00 mm at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 1 of the invention.

Figs. 13A to 13C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 3.00 mm at the telephoto end in the zoom lens according to the numerical example 1 of the invention.

Fig. 14 is a sectional view showing the construction of a zoom lens at the wide-angle end according to a numerical example 2 of the invention.

Figs. 15A to 15D are aberration diagrams showing the various aberrations at the wide-angle end in the zoom lens according to the numerical example 2 of the invention.

Figs. 16A to 16D are aberration diagrams showing the various aberrations at the focal length  $f$  of 69.79 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 17A to 17D are aberration diagrams showing the various aberrations at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 18A to 18D are aberration diagrams showing the various aberrations at the telephoto end in the zoom



lens according to the numerical example 2 of the invention.

Figs. 19A to 19C are aberration diagrams showing lateral aberrations at the wide-angle end in the zoom lens according to the numerical example 2 of the invention.

Figs. 20A to 20C are aberration diagrams showing lateral aberrations at the focal length  $f$  of 69.79 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 21A to 21C are aberration diagrams showing lateral aberrations at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 22A to 22C are aberration diagrams showing lateral aberrations at the telephoto end in the zoom lens according to the numerical example 2 of the invention.

Figs. 23A to 23C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 1.8 mm at the wide-angle end in the zoom lens according to the numerical example 2 of the invention.

Figs. 24A to 24C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 1.8 mm at the focal length  $f$  of 69.79 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 25A to 25C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit

has shifted 1.8 mm at the focal length  $f$  of 257.37 mm in the zoom lens according to the numerical example 2 of the invention.

Figs. 26A to 26C are aberration diagrams showing lateral aberrations when the image-stabilizing lens unit has shifted 1.8 mm at the telephoto end in the zoom lens according to the numerical example 2 of the invention.

Fig. 27A is an optical conceptual diagram showing an image-stabilizing zoom lens according to the invention.

Fig. 27B is an optical conceptual diagram showing the image-stabilizing zoom lens when an extender conversion optical system is inserted into the fourth lens unit.

Fig. 28 is a conceptual diagram showing the construction of a photographing apparatus having an image-stabilizing zoom lens according to a further embodiment of the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, preferred embodiments of the invention will be described in detail with reference to the drawings.

First, in a zoom lens having an image stabilizing function according to the invention, the occurrence of decentering aberration when a lens unit that is a part of the zoom lens has been moved to decenter in a direction perpendicular to the optical axis

will be discussed, from the standpoint of aberration theory, on the basis of the method shown by Matsui in the 23rd Applied Physics Lecture Meeting in Japan (1962).

The amount of aberration  $\Delta Y$  of the entire lens system occurring when a lens unit p that is a part of the photographic lens is parallel-decentered by a distance E becomes the sum of the amount of aberration  $\Delta Y$  occurring before the parallel-decentering and the amount of decentering aberration  $\Delta Y(E)$  produced by the parallel-decentering, as shown in the equation (a). Here, the amount of decentering aberration  $\Delta Y(E)$  is represented, as shown in the equation (b), by using primary decentering coma (IIE), primary decentering astigmatism (IIIE), primary decentering curvature of field (PE), primary decentering distortion (VE1), primary decentering surplus distortion (VE2) and primary original point shift  $\Delta E$ .

Also, the various aberrations (IIE) to ( $\Delta E$ ) shown in the equations (c) to (h) are represented by using aberration coefficients  $I_p$ ,  $II_p$ ,  $III_p$ ,  $P_p$  and  $V_p$  of the decentering lens unit and aberration coefficients  $I_q$ ,  $II_q$ ,  $III_q$ ,  $P_q$  and  $V_q$  of a lens system disposed on the image side of the decentering lens unit, where, when the focal length of the entire lens system is normalized to "1", an incidence angle and an exit angle of an on-axial marginal ray of light on and from the decentering lens unit are denoted by  $\alpha_p$  and  $\alpha_p'$ , respectively, and an incidence angle of a principal ray passing through the pupil center is denoted by  $\overline{\alpha_p}$ .

[illegible]

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2
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[illegible]

[illegible]

[illegible]

$$(IIE) = \alpha'_p II_q - \alpha_p (II_p + II_q) - \overline{\alpha'_p} I_q + \overline{\alpha_p} (I_p + I_q) \quad (c)$$

$$(IIIE) = \alpha'_p III_q - \alpha_p (III_p + III_q) - \overline{\alpha'_p} II_q + \overline{\alpha_p} (II_p + II_q) \quad (d)$$

$$(PE) = \alpha'_p P_q - \alpha_p (P_p + P_q) \quad (e)$$

$$(VE1) = \alpha'_p V_q - \alpha_p (V_p + V_q) - \overline{\alpha'_p} III_q + \overline{\alpha_p} (III_p + III_q) \quad (f)$$

$$(VE2) = \overline{\alpha'_p} P_q - \overline{\alpha_p} (P_p + P_q) \quad (g)$$

$$(\Delta E) = -2 (\alpha'_p - \alpha_p) \quad (h)$$

$$\Delta cYa = \Delta cY + \Delta cY(E) \quad (i)$$

$$\Delta cY = -\frac{1}{\alpha'_k} \{LR \cos \phi_R + TN \tan \omega \cos \phi_\omega\} \quad (j)$$

$$\Delta cY(E) = -\frac{E}{\alpha'_k} (TE) \quad (k)$$

$$(TE) = \alpha'_p T_q - \alpha_p (T_p + T_q) - \overline{\alpha'_p} L_q + \overline{\alpha_p} (L_p + L_q) \quad (l)$$

Among the above items, the one that represents the movement of an image caused by the decentering is the primary original point shift  $(\Delta E)$ , and the ones that influence the image forming performance are the primary decentering coma  $(IIE)$ , primary decentering astigmatism  $(IIIE)$ , primary decentering curvature of field  $(PE)$  and primary decentering chromatic aberration  $(TE)$ .

In order to lessen the occurrence of decentering

aberration, first, it is necessary to lessen the amount of decentering  $E$  of the lens unit  $p$ , as indicated in the equation (b).

In order to make the various decentering aberrations of the lens unit  $p$  shown in the equations (c) to (g) very small, it becomes necessary to set each of the various aberration coefficients  $I_p$ ,  $II_p$ ,  $III_p$ ,  $P_p$  and  $V_p$  of the lens unit  $p$  to a small value, or it becomes necessary to set the various aberration coefficients  $I_p$ ,  $II_p$ ,  $III_p$ ,  $P_p$  and  $V_p$  in a well-balanced manner in such a way as to cancel each other.

In particular, in order for each of the various decentering aberrations shown in the equations (c) to (g) to have a small value, it becomes necessary to set the converted inclination angles of a paraxial ray incident on and exiting from the parallel-decentering lens unit  $p$ , the tertiary aberration coefficients of the lens unit  $p$ , and the tertiary aberration coefficients of the whole lens unit  $q$  disposed on the image side of the lens unit  $p$ , to the respective appropriate values.

In other words, in order to eliminate the deterioration of a central image occurring when the lens unit is parallel-decentered in a direction perpendicular to the optical axis, it becomes necessary to correct well, mainly, the primary decentering coma shown in the equation (c), and, at the same time, in order to correct well one-sided blurring occurring when the lens unit is parallel-decentered, it becomes necessary to correct

well, mainly, the primary decentering curvature of field shown in the equation (d).

As a matter of course, it is necessary to correct well the other various aberrations.

In order to make the decentering chromatic aberration (TE) shown in the equation (1) very small, it becomes necessary to set the chromatic aberration coefficients of the lens unit p and the whole lens unit q disposed on the image side of the lens unit p, to the respective appropriate values.

The zoom lens having an image stabilizing function according to the invention is constructed with the above-mentioned points taken into consideration.

Next, the concrete construction of the zoom lens according to an embodiment of the invention will be described.

Fig. 27A is a conceptual diagram of the zoom lens having an image stabilizing function. In Fig. 27A, reference character F denotes a focusing lens unit (front lens unit), serving as a first lens unit, of positive refractive power.

Reference character V denotes a variator, serving as a second lens unit, of negative refractive power for the variation of magnification. The variation of magnification from the wide-angle end to the telephoto end is effected by moving the variator V monotonically toward the image side along the optical axis.

Reference character C denotes a compensator,

serving as a third lens unit, of positive refractive power, which is arranged to move nonlinearly toward the object side along the optical axis so as to compensate for the shift of an image plane caused by the variation of magnification. The variator V and the compensator C constitute a magnification varying system. Incidentally, the compensator C may be of negative refractive power. Reference character SP denotes a stop, and reference character R denotes a stationary relay lens unit, serving as a fourth lens unit, of positive refractive power as a whole. The relay lens unit R is composed of a lens subunit 4F of negative refractive power and a lens subunit 4R of positive refractive power.

As shown in Fig. 27A, an image point I' formed by the lens unit F through the lens unit C does not vary in position during the variation of magnification. Accordingly, taking into consideration the image forming relationship of the relay lens unit R only, the arrangement and the paraxial tracing value of the relay lens unit R are unvaried irrespective of the variation of magnification. Therefore, by disposing the image-stabilizing lens unit in a lens unit disposed on the image side of the magnification varying lens units and arranged to be stationary during the variation of magnification, it is possible to prevent the variation of the various decentering aberrations due to the variation of magnification.

Further, by using, as the image-stabilizing lens



unit, the lens subunit 4F of negative refractive power disposed on the object side of the lens subunit 4R of positive refractive power, or a lens unit that is a part of the lens subunit 4F, it is possible to reduce the effective diameter of the image-stabilizing lens unit, thereby attaining the reduction in size and weight of the image-stabilizing lens unit and the reduction in size of the whole image stabilizing device.

According to the embodiment of the invention, the zoom lens further has the following characteristic features, thereby obtaining the more advantageous effects.

First, the conditions under which the image-stabilizing lens unit is made small in size and light in weight and is made optimum in terms of optical performance will be described in the following. The amount of decentering  $E_4$ s of the image-stabilizing lens unit required for obtaining a predetermined amount of image-shake correction  $\Delta Y$  on an image plane is expressed by the following equation (m) on the basis of the equation (b) with  $R = 0$ ,  $\omega = 0$  and  $\alpha_k' = 1$ .

$$E_{4s} = -\Delta Y / \{2(\Delta E)\} \quad \dots (m)$$

Since the primary original point shift ( $\Delta E$ ) is expressed by the equation (h), the amount of decentering E4s required for obtaining a necessary amount of image-shake correction  $\Delta Y$  is defined by using a converted inclination angle of incidence  $\alpha$  and a converted inclination angle of exit  $\alpha'$  of an on-axial marginal ray

on and from the image-stabilizing lens unit. Accordingly, the zoom lens is made to satisfy the following condition (1):

$$\alpha' - \alpha < -0.45 \quad \dots(1)$$

If the condition (1) is not satisfied, the increase of the amount of decentering E4s causes the amount of movement of the image-stabilizing lens unit to increase rapidly, and, in addition, the effective diameter of the image-stabilizing lens unit is increased in consideration of the decentering, so that the required driving force increases rapidly, resulting in an increase in size of the whole mechanism. Further, in association with the increase of the amount of decentering E4s, the occurrence of decentering aberration becomes large, so that the optical performance during the image stabilizing operation deteriorates.

In addition, the image-stabilizing lens unit may be composed of one negative lens. However, since, from the viewpoint of the equations (c) to (g), in order to correct decentering aberrations caused by the image-stabilizing lens unit, it is necessary to appropriately control the various shared values of aberration coefficients of the image-stabilizing lens unit, it is preferable that the image-stabilizing lens unit is composed of at least one positive lens and at least one negative lens. By this arrangement, it becomes easy to control the various shared values of aberration coefficients of the image-stabilizing lens unit. Thus,

it becomes easy to correct decentering aberrations, so that the various decentering aberrations, such as decentering coma and decentering curvature of field, can be prevented from easily occurring during the image stabilizing operation. It is more preferable that the image-stabilizing lens unit consists of one positive lens and one negative lens or consists of one positive lens and two negative lenses.

Further, from the viewpoint of the equation (1), in order to correct decentering chromatic aberrations caused by the image-stabilizing lens unit, it is necessary to appropriately control the various shared values of chromatic aberration coefficients of the image-stabilizing lens unit.

Accordingly, the zoom lens is made to satisfy the following condition (2):

$$v_n(4S) - v_p(4S) > 10 \quad \dots(2)$$

where  $v_n(4S)$  is, when the image-stabilizing lens unit includes only one negative lens, an Abbe number of material of the negative lens included in the image-stabilizing lens unit or, when the image-stabilizing lens unit includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in the image-stabilizing lens unit, and  $v_p(4S)$  is, when the image-stabilizing lens unit includes only one positive lens, an Abbe number of material of the positive lens included in the image-stabilizing lens unit or, when the image-stabilizing lens unit includes a

plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in the image-stabilizing lens unit.

If the condition (2) is not satisfied, it becomes difficult to control the various chromatic aberration coefficients of the image-stabilizing lens unit. Thus, it becomes difficult to correct decentering chromatic aberrations, so that the asymmetry of color becomes apt to occur during the image stabilizing operation.

Next, the conditions for the lens subunit 4R appropriate in terms of optical performance will be described in the following.

From the viewpoint of the equations (c) to (g), in order to correct decentering aberrations caused by the image-stabilizing lens unit, it is necessary to appropriately control the various shared values of aberration coefficients of a lens unit disposed on the image side of the image-stabilizing lens unit.

Accordingly, if the lens subunit 4R disposed on the image side of the image-stabilizing lens unit is not made to be composed of at least one positive lens and at least one negative lens, it becomes difficult to control the various shared values of aberration coefficients. Thus, it becomes difficult to correct decentering aberrations, so that the various decentering aberrations, such as decentering coma and decentering curvature of field, become apt to occur.

Further, from the viewpoint of the equation (1), in order to correct decentering chromatic aberrations caused by the image-stabilizing lens unit, it is necessary to appropriately control the various shared values of chromatic aberration coefficients of a lens unit disposed on the image side of the image-stabilizing lens unit. Accordingly, the zoom lens is made to satisfy the following condition (3):

$$vp(4R) - vn(4R) > 10 \quad \dots(3)$$

where  $vp(4R)$  is, when the lens subunit 4R includes only one positive lens, an Abbe number of material of the positive lens included in the lens subunit 4R or, when the lens subunit 4R includes a plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in the lens subunit 4R, and  $vn(4R)$  is, when the lens subunit 4R includes only one negative lens, an Abbe number of material of the negative lens included in the lens subunit 4R or, when the lens subunit 4R includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in the lens subunit 4R.

If the condition (3) is not satisfied, it becomes difficult to control the various chromatic aberration coefficients of the lens subunit 4R disposed on the image side of the image-stabilizing lens unit. Thus, it becomes difficult to correct decentering chromatic aberrations of the image-stabilizing lens unit, so that the asymmetry of color becomes apt to occur

during the image stabilizing operation.

Further, in the zoom lens according to the embodiment of the invention, such a high zoom ratio as 40× or more is attained by effecting the variation of lateral magnification with the third lens unit as well as the second lens unit. For that purpose, an image forming magnification of the second lens unit varies within a range including -1× during the variation of magnification, an image forming magnification of the third lens unit varies within a range including -1× during the variation of magnification, and the following conditions are satisfied:

$$5 < Z2 \quad \dots(4)$$

$$0.15 < Z2 / Z \quad \dots(5)$$

where Z2 is a rate of variation of lateral magnification of the second lens unit, and Z is a zoom ratio of the zoom lens.

If the conditions (4) and (5) are not satisfied, it becomes difficult to obtain a zoom lens having a high variable magnification ratio.

Further, in the zoom lens according to embodiment of the invention, an optical system (4E) for shifting the range of variable magnification toward the telephoto side or the wide-angle side may be made to be located on the image side of the image-stabilizing lens unit by such a unit switching method as to detachably insert a lens unit, such as a built-in extender conversion optical system. In that instance, it is

unnecessary to change the control of the image-stabilizing lens unit before and after the shift of the range of variable magnification. Fig. 27B is an optical conceptual diagram showing the zoom lens when the extender conversion optical system (focal-length conversion optical system) 4E is inserted in a position on the image side of the image-stabilizing lens unit. Since, as shown in Fig. 27B, the disposition of lens units on the object side of the image-stabilizing lens unit does not change before and after the shift of the focal length due to the insertion or detachment of the extender conversion optical system 4E, the amount of decentering E of the image-stabilizing lens unit required for obtaining a desired correction angle  $\theta$  also does not change, so that it is unnecessary to change the control of the image-stabilizing lens unit.

Next, the construction of each of zoom lenses according to numerical examples 1 and 2 of the invention will be described.

Fig. 1 is a sectional view showing the construction of a zoom lens at the wide-angle end according to the numerical example 1 of the invention. In Fig. 1, reference character F denotes a focusing lens unit (front lens unit), serving as a first lens unit, of positive refractive power. Reference character V denotes a variator, serving as a second lens unit, of negative refractive power for the variation of magnification. The variation of magnification from the wide-angle end to the

telephoto end is effected by moving the variator V monotonically toward the image side along the optical axis.

Reference character C denotes a compensator, serving as a third lens unit, of positive refractive power, which is arranged to move nonlinearly toward the object side along the optical axis so as to compensate for the shift of an image plane caused by the variation of magnification. The variator V and the compensator C constitute a magnification varying system.

Reference character SP denotes a stop, and reference character R denotes a stationary relay lens unit, serving as a fourth lens unit, of positive refractive power as a whole. Reference character P denotes a color separation prism, an optical filter or the like, which is illustrated as a glass block in Fig. 1.

The fourth lens unit is composed of a lens subunit 4F of negative refractive power and a lens subunit 4R of positive refractive power. The whole lens subunit 4F serves as the image-stabilizing lens unit, having the function of moving in a direction perpendicular to the optical axis for the purpose of stabilizing an image.

The image-stabilizing lens unit is composed of one negative lens and one positive lens. When a converted inclination angle of incidence of a light flux on the image-stabilizing lens unit is denoted by  $\alpha$ , a



converted inclination angle of exit of a light flux from the image-stabilizing lens unit 4S denoted by  $\alpha'$ , an Abbe number of material of the negative lens of the image-stabilizing lens unit is denoted by  $\nu_n(4S)$ , and an Abbe number of material of the positive lens of the image-stabilizing lens unit is denoted by  $\nu_p(4S)$ , the above-mentioned conditions (1) and (2) are satisfied as shown by the following values:

$$\alpha' - \alpha = -0.503$$

$$\nu_n(4S) - \nu_p(4S) = 22.7$$

$$(\nu_n(4S) = 46.6,$$

$$\nu_p(4S) = 23.9)$$

Further, the lens subunit 4R is composed of five positive lenses and three negative lenses. When a mean value of Abbe numbers of material of the positive lenses of the lens subunit 4R is denoted by  $\nu_p(4R)$ , and a mean value of Abbe numbers of material of the negative lenses of the lens subunit 4R is denoted by  $\nu_n(4R)$ , the above-mentioned condition (3) is satisfied as shown by the following values:

$$\nu_p(4R) - \nu_n(4R) = 12.1$$

$$(\nu_p(4R) = 53.5,$$

$$\nu_n(4R) = 41.4)$$

Further, the various decentering aberration coefficients, factors, etc., corresponding to the above equations (c) to (h) and (l) are listed in Table-1 with the image-stabilizing lens unit denoted by p, and the lens unit disposed on the image side of the image-

stabilizing lens unit denoted by  $q$ .

By appropriately setting the converted inclination angles of incidence and exit on and from the image-stabilizing lens unit, and the shared values of aberration coefficients of the image-stabilizing lens unit and the lens unit disposed on the image side of the image-stabilizing lens unit, it is possible to make the decentering aberration coefficients of the image-stabilizing lens unit very small.

Table-1

$\alpha_p$	1.0492	$L_p$	0.0201	$L_q$	-0.0233	TE	-0.0037
$\alpha_p'$	0.5167	$T_p$	0.0008	$T_q$	-0.0025	IIE	-0.0140
$\overline{\alpha_p}$	-0.1917	$I_p$	-7.6750	$I_q$	0.7828	IIIE	0.0015
$\overline{\alpha_p'}$	-0.2024	$II_p$	1.3426	$II_q$	0.1600	PE	0.0017
		$III_p$	-0.0682	$III_q$	-0.3485	VE1	0.0198
		$P_p$	-0.0636	$P_q$	0.1221	VE2	-0.0135
		$V_p$	-0.0053	$V_q$	-0.00919	$\Delta E$	1.0651

The rate of variation  $Z2$  of lateral magnification of the second lens unit is 9.21, and the zoom ratio  $Z$  is 44.1, so that the above conditions (4) and (5) are satisfied.

Figs. 2A to 2D through Figs. 5A to 5D are aberration diagrams showing the various longitudinal aberrations at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens

according to the numerical example 1.

Figs. 6A to 6C through Figs. 9A to 9C are aberration diagrams showing lateral aberrations, with the image height being 0 mm and  $\pm 4$  mm, at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens according to the numerical example 1.

Figs. 10A to 10C through Figs. 13A to 13C are aberration diagrams showing lateral aberrations, with the image height being 0 mm and  $\pm 4$  mm, when the image stabilizing lens unit has shifted at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens according to the numerical example 1.

Incidentally, while, in the numerical example 1, the image-stabilizing lens unit is composed of the whole lens subunit  $4F$ , this arrangement may be changed to such a construction that the lens subunit  $4F$ , with the number of constituent lenses thereof increased, is divided into a plurality of lens units and a certain lens unit among the plurality of lens units is made to be the image-stabilizing lens unit.

As described above, in the numerical example 1, the refractive power arrangement of the entire lens system, the arrangement of the magnification varying lens units and the arrangement of the image-stabilizing lens unit in the fourth lens unit are appropriately set, and the lens construction of the image-stabilizing lens unit

is also appropriately set. Accordingly, it is possible to obtain high optical performance over the entire range of variable magnification even during the image stabilizing operation.

Fig. 14 is a sectional view showing the construction of a zoom lens at the wide-angle end according to a numerical example 2 of the invention. In Fig. 14, reference character F denotes a focusing lens unit (front lens unit), serving as a first lens unit, of positive refractive power.

Reference character V denotes a variator, serving as a second lens unit, of negative refractive power for the variation of magnification. The variation of magnification from the wide-angle end to the telephoto end is effected by moving the variator V monotonically toward the image side along the optical axis. Reference character C denotes a compensator, serving as a third lens unit, of positive refractive power, which is arranged to move nonlinearly toward the object side along the optical axis so as to compensate for the shift of an image plane caused by the variation of magnification. The variator V and the compensator C constitute a magnification varying system.

Reference character SP denotes a stop, and reference character R denotes a stationary relay lens unit, serving as a fourth lens unit, of positive refractive power as a whole. Reference character P denotes a color separation prism, an optical filter or

the like, which is illustrated as a glass block in Fig. 14.

The fourth lens unit is composed of a lens subunit 4F of negative refractive power and a lens subunit 4R of positive refractive power. The whole lens subunit 4F serves as the image-stabilizing lens unit, having the function of moving in a direction perpendicular to the optical axis for the purpose of stabilizing an image. The image-stabilizing lens unit is composed of two negative lenses and one positive lens. When a converted inclination angle of incidence of a light flux on the image-stabilizing lens unit is denoted by  $\alpha$ , a converted inclination angle of exit of a light flux from the image-stabilizing lens unit is denoted by  $\alpha'$ , a mean value of Abbe numbers of material of the negative lenses of the image-stabilizing lens unit is denoted by  $\nu_n(4S)$ , and an Abbe number of material of the positive lens of the image-stabilizing lens unit is denoted by  $\nu_p(4S)$ , the above-mentioned conditions (1) and (2) are satisfied as shown by the following values:

$$\alpha' - \alpha = -0.848$$

$$\nu_n(4S) - \nu_p(4S) = 12.5$$

$$(\nu_n(4S) = 40.8,$$

$$\nu_p(4S) = 28.3)$$

Further, the lens subunit 4R is composed of five positive lenses and three negative lenses. When a mean value of Abbe numbers of material of the positive lenses of the lens subunit 4R is denoted by  $\nu_p(4R)$ , and a mean

value of Abbe numbers of material of the negative lenses of the lens subunit 4R is denoted by  $\nu_n(4R)$ , the above-mentioned condition (3) is satisfied as shown by the following values:

$$\begin{aligned}\nu_p(4R) - \nu_n(4R) &= 11.9 \\ (\nu_p(4R) &= 53.3, \\ \nu_n(4R) &= 41.4)\end{aligned}$$

Further, the various decentering aberration coefficients, factors, etc., corresponding to the above equations (c) to (h) and (l) are listed in Table-2 with the image-stabilizing lens unit denoted by p, and the lens unit disposed on the image side of the image-stabilizing lens unit denoted by q.

By appropriately setting the converted inclination angles of incidence and exit on and from the image-stabilizing lens unit, and the shared values of aberration coefficients of the image-stabilizing lens unit and the lens unit disposed on the image side of the image-stabilizing lens unit, it is possible to make the decentering aberration coefficients of the image-stabilizing lens unit very small.

Table-2

$\alpha_p$	1.0492	$L_p$	0.0244	$L_q$	-0.0270	TE	-0.0036
$\alpha_p'$	0.2007	$T_p$	0.0021	$T_q$	-0.0048	IIE	0.0237
$\overline{\alpha_p}$	-0.1917	$I_p$	-8.2768	$I_q$	1.7561	IIIE	0.0014
$\overline{\alpha_p'}$	-0.2211	$II_p$	1.8845	$II_q$	-0.4273	PE	-0.0547
		$III_p$	-0.1049	$III_q$	-0.3243	VE1	0.0283
		$P_p$	-0.0796	$P_q$	0.1628	VE2	-0.0200
		$V_p$	-0.0155	$V_q$	-0.0018	$\Delta E$	1.6971

The rate of variation  $Z_2$  of lateral magnification of the second lens unit is 9.21, and the zoom ratio  $Z$  is 44.1, so that the above conditions (4) and (5) are satisfied.

Figs. 15A to 15D through Figs. 18A to 18D are aberration diagrams showing the various longitudinal aberrations at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens according to the numerical example 2.

Figs. 19A to 19C through Figs. 22A to 22C are aberration diagrams showing lateral aberrations, with the image height being 0 mm and  $\pm 4$  mm, at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens according to the numerical example 2.

Figs. 23A to 23C through Figs. 26A to 26C are aberration diagrams showing lateral aberrations, with the image height being 0 mm and  $\pm 4$  mm, when the image

stabilizing lens unit has shifted at the wide-angle end, at the focal length  $f$  of 69.79 mm, at the focal length  $f$  of 257.37 mm and at the telephoto end, respectively, in the zoom lens according to the numerical example 2.

Incidentally, while, in the numerical example 2, the image-stabilizing lens unit is composed of the whole lens subunit  $4F$ , this arrangement may be changed to such a construction that the lens subunit  $4F$ , with the number of constituent lenses thereof increased, is divided into a plurality of lens units and a certain lens unit among the plurality of lens units is made to be the image-stabilizing lens unit.

As described above, in the numerical example 2, the refractive power arrangement of the entire lens system, the arrangement of the magnification varying lens units and the arrangement of the image-stabilizing lens unit in the fourth lens unit are appropriately set, and the lens construction of the image-stabilizing lens unit is also appropriately set. Accordingly, it is possible to obtain high optical performance over the entire range of variable magnification even during the image stabilizing operation.

Next, numerical data of the numerical examples 1 and 2 of the invention are shown. In the numerical data of the numerical examples 1 and 2,  $r_i$  is the radius of curvature of the  $i$ -th lens surface, when counted from the object side,  $d_i$  is the  $i$ -th lens thickness or air separation, when counted from the object side, and  $n_i$  and



$v_i$  are respectively the refractive index and Abbe number of glass of the  $i$ -th lens element, when counted from the object side.

In the numerical examples 1 and 2, the last two lens surfaces constitute a glass block, such as a face plate or a filter.

#### Numerical Example 1:

$f = 9.99978$      $F_{no} = 1:1.8 - 3.3$      $2\omega = 57.6^\circ - 1.4^\circ$

$r_1 = 262.527$	$d_1 = 5.50$	$n_1 = 1.83932$	$v_1 = 37.2$
$r_2 = 148.600$	$d_2 = 0.20$		
$r_3 = 146.720$	$d_3 = 19.47$	$n_2 = 1.43496$	$v_2 = 95.1$
$r_4 = 1711.919$	$d_4 = 11.35$		
$r_5 = 446.535$	$d_5 = 12.04$	$n_3 = 1.43496$	$v_3 = 95.1$
$r_6 = -528.168$	$d_6 = 0.07$		
$r_7 = -522.929$	$d_7 = 5.00$	$n_4 = 1.77621$	$v_4 = 49.6$
$r_8 = -7601.809$	$d_8 = 0.30$		
$r_9 = 189.702$	$d_9 = 18.57$	$n_5 = 1.43496$	$v_5 = 95.1$
$r_{10} = -890.210$	$d_{10} = 0.30$		
$r_{11} = 150.001$	$d_{11} = 11.18$	$n_6 = 1.49845$	$v_6 = 81.6$
$r_{12} = 393.239$	$d_{12} = \text{Variable}$		
$r_{13} = 521.146$	$d_{13} = 2.00$	$n_7 = 1.77621$	$v_7 = 49.6$
$r_{14} = 53.105$	$d_{14} = 4.73$		
$r_{15} = -148.563$	$d_{15} = 1.80$	$n_8 = 1.77621$	$v_8 = 49.6$
$r_{16} = 51.373$	$d_{16} = 6.72$		
$r_{17} = -66.261$	$d_{17} = 1.80$	$n_9 = 1.79025$	$v_9 = 50.0$
$r_{18} = 47.388$	$d_{18} = 7.80$	$n_{10} = 1.93306$	$v_{10} = 21.3$
$r_{19} = -366.607$	$d_{19} = \text{Variable}$		

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r20=	633.050	d20=	6.36	n11=	1.43985	v11=	95.0
r21=	-113.045	d21=	0.30				
r22=	201.150	d22=	2.50	n12=	1.65223	v12=	33.8
r23=	53.110	d23=	13.60	n13=	1.59143	v13=	61.2
r24=	-155.230	d24=	0.20				
r25=	131.701	d25=	13.00	n14=	1.62032	v14=	63.4
r26=	-75.433	d26=	2.50	n15=	1.85501	v15=	23.9
r27=	-155.034	d27=	0.20				
r28=	95.626	d28=	4.25	n16=	1.48915	v16=	70.2
r29=	293.766	d29=	Variable				
r30=	(Stop)	d30=	3.29				
r31=	-106.669	d31=	1.80	n17=	1.82017	v17=	46.6
r32=	47.175	d32=	0.18				
r33=	38.336	d33=	3.81	n18=	1.85501	v18=	23.9
r34=	100.002	d34=	5.39				
r35=	-30.196	d35=	1.60	n19=	1.73234	v19=	54.7
r36=	26.193	d36=	17.64	n20=	1.57047	v20=	42.8
r37=	-28.031	d37=	19.00				
r38=	-99.571	d38=	5.20	n21=	1.51977	v21=	52.4
r39=	-27.773	d39=	0.20				
r40=	-36.155	d40=	2.20	n22=	1.79013	v22=	44.2
r41=	35.022	d41=	7.02	n23=	1.55099	v23=	45.8
r42=	-61.501	d42=	1.10				
r43=	78.384	d43=	7.60	n24=	1.48915	v24=	70.2
r44=	-32.064	d44=	2.20	n25=	1.81265	v25=	25.4
r45=	-69.443	d45=	0.20				
r46=	73.620	d46=	4.59	n26=	1.50349	v26=	56.4
r47=	-82.081	d47=	5.00				

r48=  $\infty$       d48= 50.00      n27= 1.51825      v27= 64.2  
r49=  $\infty$

Variable Separation	Focal Length			
	10.00	69.79	257.36	441.09
d12	2.37	92.37	115.87	121.38
d19	176.20	67.02	19.71	0.14
d29	3.30	22.48	46.29	60.36

# Numerical Example 2:

f= 10.00000      Fno= 1:1.8 - 3.1       $2\omega = 57.6^\circ - 1.4^\circ$   
r 1= 262.527      d 1= 5.50      n 1= 1.83932      v 1= 37.2  
r 2= 148.600      d 2= 0.20  
r 3= 146.720      d 3= 19.47      n 2= 1.43496      v 2= 95.1  
r 4= 1711.919      d 4= 11.35  
r 5= 446.535      d 5= 12.04      n 3= 1.43496      v 3= 95.1  
r 6= -528.168      d 6= 0.07  
r 7= -522.929      d 7= 5.00      n 4= 1.77621      v 4= 49.6  
r 8= -7601.809      d 8= 0.30  
r 9= 189.702      d 9= 18.57      n 5= 1.43496      v 5= 95.1  
r10= -890.210      d10= 0.30  
r11= 150.001      d11= 11.18      n 6= 1.49845      v 6= 81.6  
r12= 393.239      d12= Variable  
r13= 521.146      d13= 2.00      n 7= 1.77621      v 7= 49.6  
r14= 53.105      d14= 4.73  
r15= -148.563      d15= 1.80      n 8= 1.77621      v 8= 49.6  
r16= 51.373      d16= 6.72  
r17= -66.261      d17= 1.80      n 9= 1.79025      v 9= 50.0

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r18=	47.388	d18=	7.80	n10=	1.93306	v10=	21.3
r19=	-366.607	d19=	Variable				
r20=	633.050	d20=	6.36	n11=	1.43985	v11=	95.0
r21=	-113.045	d21=	0.30				
r22=	201.150	d22=	2.50	n12=	1.65223	v12=	33.8
r23=	53.110	d23=	13.60	n13=	1.59143	v13=	61.2
r24=	-155.230	d24=	0.20				
r25=	131.701	d25=	13.00	n14=	1.62032	v14=	63.4
r26=	-75.433	d26=	2.50	n15=	1.85501	v15=	23.9
r27=	-155.034	d27=	0.20				
r28=	95.626	d28=	4.25	n16=	1.48915	v16=	70.2
r29=	293.766	d29=	Variable				
r30=	(Stop)	d30=	3.29				
r31=	-98.009	d31=	1.80	n17=	1.88814	v17=	40.8
r32=	42.998	d32=	0.20				
r33=	30.611	d33=	9.58	n18=	1.74618	v18=	28.3
r34=	-32.609	d34=	1.80	n19=	1.88814	v19=	40.8
r35=	96.858	d35=	7.48				
r36=	-42.629	d36=	1.60	n20=	1.73234	v20=	54.7
r37=	27.958	d37=	15.00	n21=	1.57047	v21=	42.8
r38=	-33.727	d38=	19.00				
r39=	-166.259	d39=	4.99	n22=	1.48915	v22=	70.2
r40=	-28.835	d40=	0.20				
r41=	-36.826	d41=	2.20	n23=	1.79013	v23=	44.2
r42=	63.095	d42=	6.18	n24=	1.50349	v24=	56.4
r43=	-47.677	d43=	1.10				
r44=	81.999	d44=	8.25	n25=	1.55099	v25=	45.8
r45=	-29.154	d45=	2.20	n26=	1.81265	v26=	25.4

r46= -92.720    d46= 0.20  
 r47= 73.620    d47= 5.00    n27= 1.51977    v27= 52.4  
 r48= -82.081    d48= 5.00  
 r49=  $\infty$     d49= 50.00    n28= 1.51825    v28= 64.2  
 r50=  $\infty$

Variable Separation	Focal Length				
	10.00	19.49	69.79	257.37	441.10
d12	2.37	44.37	92.37	115.87	121.38
d19	176.20	129.14	67.02	19.71	0.14
d29	3.30	8.36	22.48	46.29	60.36

Next, a photographing apparatus having a zoom lens including the image-stabilizing lens unit as described above, according to another embodiment of the invention, will be described with reference to Fig. 28, which is a schematic diagram showing the photographing apparatus. In Fig. 28, reference numeral 1 denotes a photographing optical system using a zoom lens according to the embodiment of the invention, reference numeral 2 denotes a photoelectric conversion means such as a CCD, and reference numeral 3 denotes a photographing apparatus body (casing). By applying the zoom lens having the image-stabilizing lens unit according to the embodiment of the invention to the photographing optical system of the photographing apparatus, as described in the foregoing, it is possible to realize a photographing apparatus which is compact and has high optical

performance even during the image stabilizing operation.

As described above, according to the invention, it is possible to attain a zoom lens having an image stabilizing function suited for the so-called four-unit zoom lens, in which the shaking of a photographed image is corrected by driving a lens unit that is a part of the zoom lens to decenter in a direction perpendicular to the optical axis, and each lens element of the zoom lens is appropriately set to reduce the size of the image-stabilizing lens unit and to correct well the various aberrations and decentering aberration.

In addition, according to the invention, in the so-called four-unit zoom lens, the refractive power arrangement of the entire lens system, the arrangement of the magnification varying lens units and the arrangement of the fourth lens unit are appropriately set. Accordingly, it is possible to attain a zoom lens having an image stabilizing function with the whole mechanism therefor reduced in size and weight and having high optical performance over the entire range of variable magnification even during the image stabilizing operation.

CLAIMS

1. A zoom lens comprising, in order from an object side to an image side:

a first lens unit of positive refractive power;

a second lens unit of negative refractive power arranged to move during variation of magnification;

a third lens unit arranged to compensate for shift of an image plane due to the variation of magnification; and

a fourth lens unit of positive refractive power,

wherein said fourth lens unit has a first lens subunit of negative refractive power, and an image is displaced by moving said first lens subunit in such a way as to have a component perpendicular to an optical axis of said zoom lens.

2. A zoom lens according to claim 1, wherein said first lens subunit consists of one positive lens and one negative lens.

3. A zoom lens according to claim 1, wherein said first lens subunit consists of one positive lens and two negative lenses.

4. A zoom lens according to claim 1, wherein said fourth lens unit further has a second lens subunit of positive refractive power on the image side of said first

lens subunit.

5. A zoom lens according to claim 4, wherein said third lens unit is of positive refractive power, and said fourth lens unit consists of, in order from the object side to the image side, said first lens subunit of negative refractive power and said second lens subunit of positive refractive power.

6. A zoom lens according to claim 4, wherein the following condition is satisfied:

$$\alpha' - \alpha < -0.45$$

where  $\alpha$  is a converted inclination angle of incidence on a lens surface on the most object side of said first lens subunit, and  $\alpha'$  is a converted inclination angle of exit from a lens surface on the most image side of said first lens subunit.

7. A zoom lens according to claim 4, wherein the following condition is satisfied:

$$vn(4S) - vp(4S) > 10$$

where  $vn(4S)$  is, when said first lens subunit includes only one negative lens, an Abbe number of material of the negative lens included in said first lens subunit or, when said first lens subunit includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in said first lens subunit, and  $vp(4S)$  is, when said first lens subunit



includes only one positive lens, an Abbe number of material of the positive lens included in said first lens subunit or, when said first lens subunit includes a plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in said first lens subunit.

8. A zoom lens according to claim 4, wherein the following condition is satisfied:

$$v_p(4R) - v_n(4R) > 10$$

where  $v_p(4R)$  is, when said second lens subunit includes only one positive lens, an Abbe number of material of the positive lens included in said second lens subunit or, when said second lens subunit includes a plurality of positive lenses, a mean value of Abbe numbers of material of all the positive lenses included in said second lens subunit, and  $v_n(4R)$  is, when said second lens subunit includes only one negative lens, an Abbe number of material of the negative lens included in said second lens subunit or, when said second lens subunit includes a plurality of negative lenses, a mean value of Abbe numbers of material of all the negative lenses included in said second lens subunit.

9. A zoom lens according to claim 1, wherein an image forming magnification of said second lens unit varies within a range including  $-1\times$  during the variation of magnification, an image forming magnification of said

third lens unit varies within a range including  $-1\times$  during the variation of magnification, and the following conditions are satisfied:

$$5 < Z2$$

$$0.15 < Z2 / Z$$

where  $Z2$  is a rate of variation of lateral magnification of said second lens unit, and  $Z$  is a zoom ratio of said zoom lens.

10. A zoom lens according to claim 1, wherein an extender conversion optical system for varying the focal length of said zoom lens is insertably and detachably disposed in a position on the image side of said first lens subunit.

11. A photographing apparatus comprising:  
a zoom lens according to claim 1; and  
a casing holding said zoom lens.

ABSTRACT OF THE DISCLOSURE

A zoom lens includes, in order from an object side to an image side, a first lens unit of positive refractive power, a second lens unit of negative refractive power arranged to move during variation of magnification, a third lens unit arranged to compensate for shift of an image plane due to the variation of magnification, and a fourth lens unit of positive refractive power, wherein the fourth lens unit has a first lens subunit of negative refractive power, and an image is displaced by moving the first lens subunit in such a way as to have a component perpendicular to an optical axis of the zoom lens.

FIG. 1

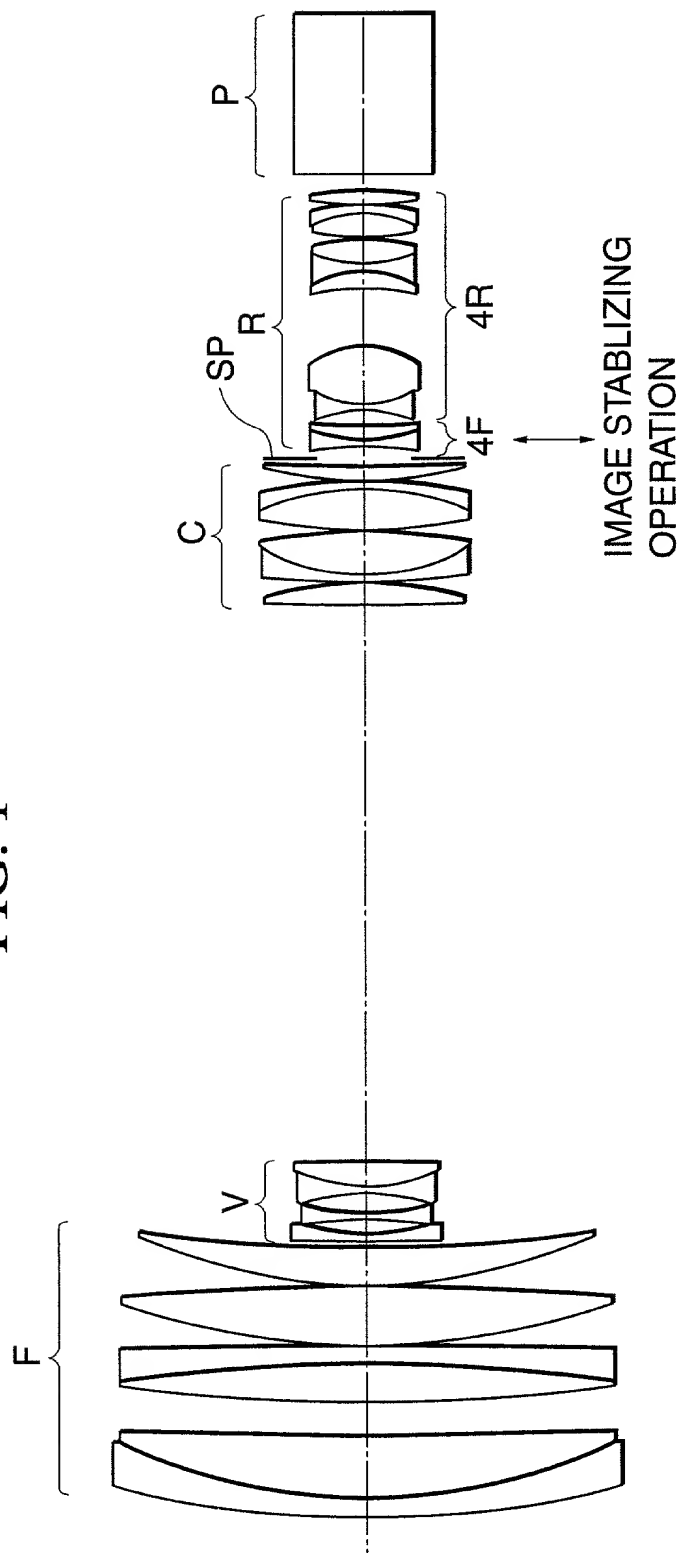


FIG. 2A

$F_{no}/1.8$

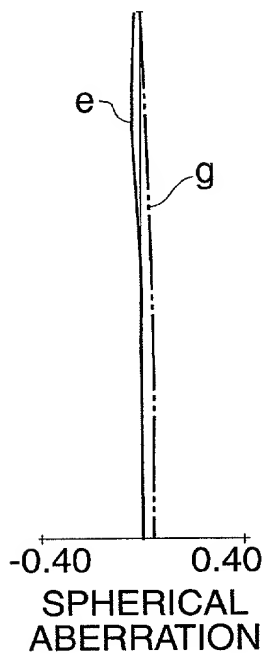


FIG. 2B

$\omega=28.8^\circ$

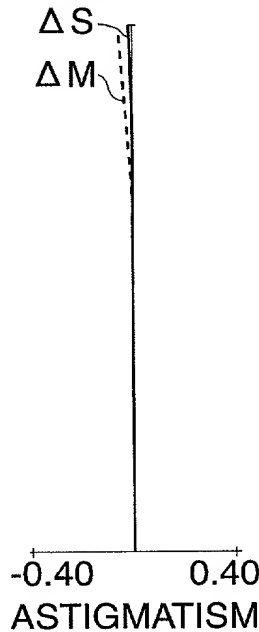


FIG. 2C

$\omega=28.8^\circ$

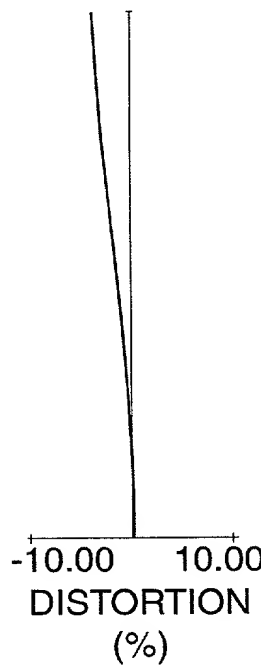


FIG. 2D

$\omega=28.8^\circ$

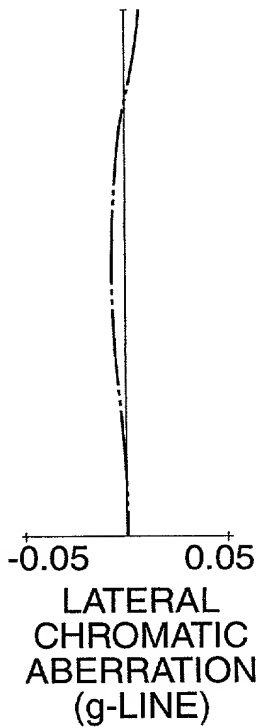


FIG. 3A

$F_{no}/1.8$

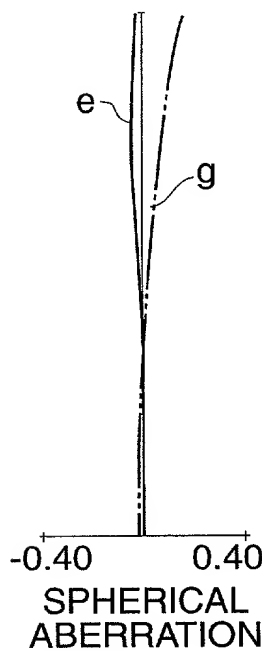


FIG. 3B

$\omega=4.5^\circ$

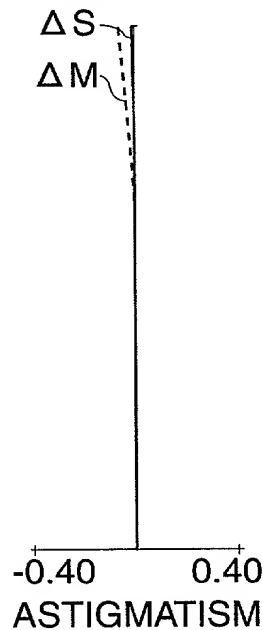


FIG. 3C

$\omega=4.5^\circ$

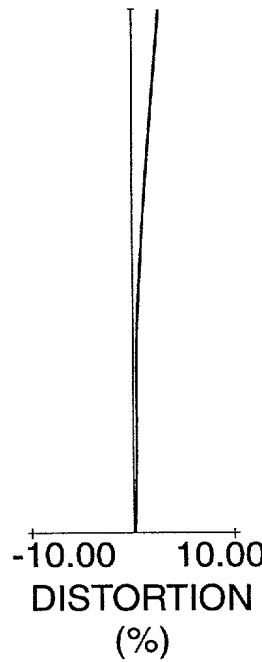


FIG. 3D

$\omega=4.5^\circ$

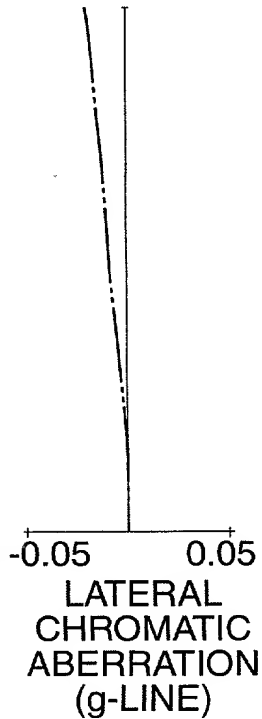


FIG. 4A

Fno/1.8

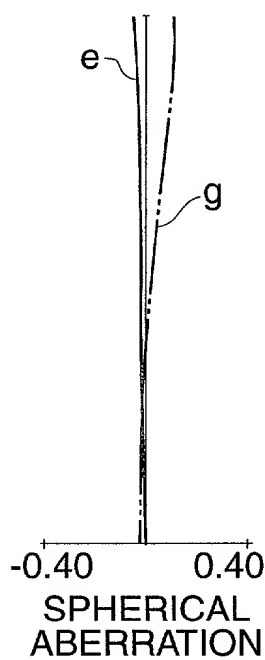


FIG. 4B

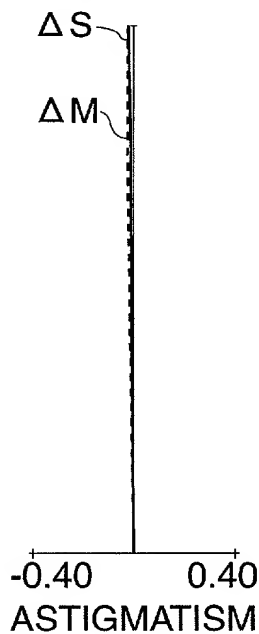
 $\omega = 1.2^\circ$ 

FIG. 4C

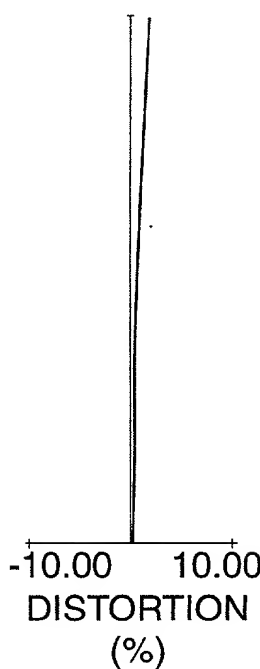
 $\omega = 1.2^\circ$ 

FIG. 4D

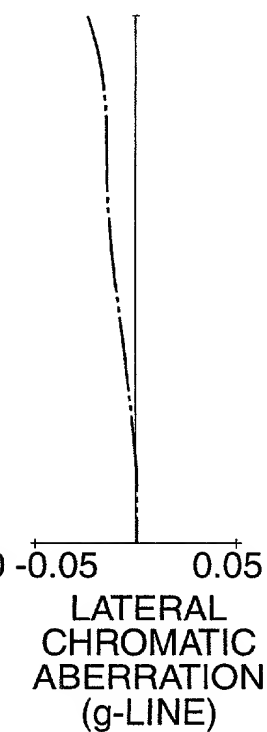
 $\omega = 1.2^\circ$ 

FIG. 5A

**Fno/3.1**

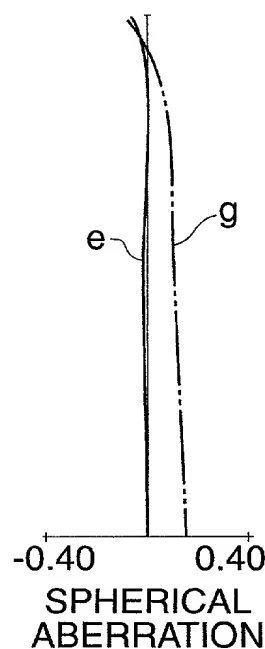


FIG. 5B

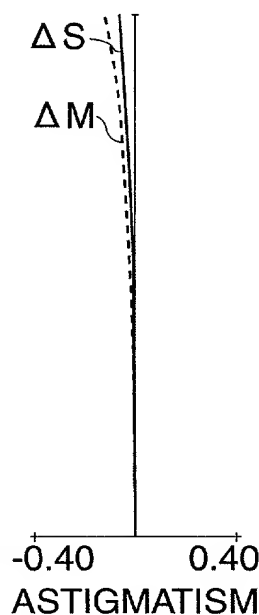
 $\omega = 0.71^\circ$ 

FIG. 5C

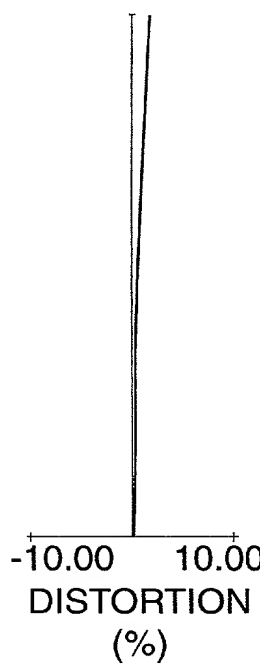
 $\omega = 0.71^\circ$ 

FIG. 5D

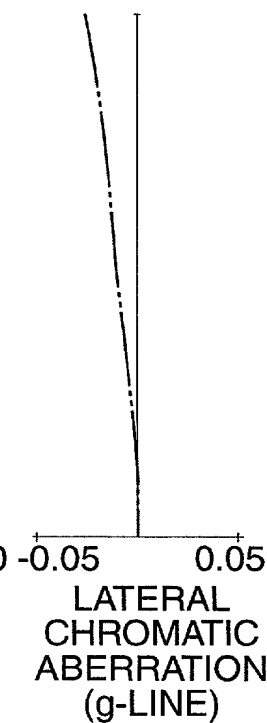
 $\omega = 0.71^\circ$ 

FIG. 6A

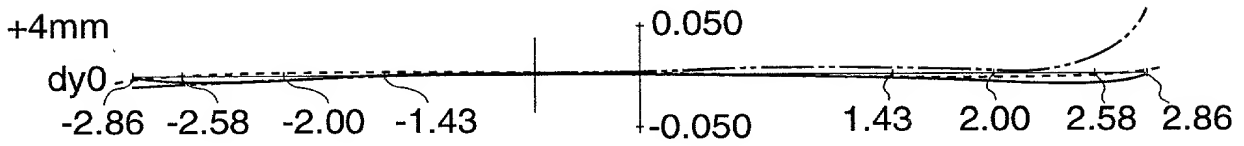


FIG. 6B

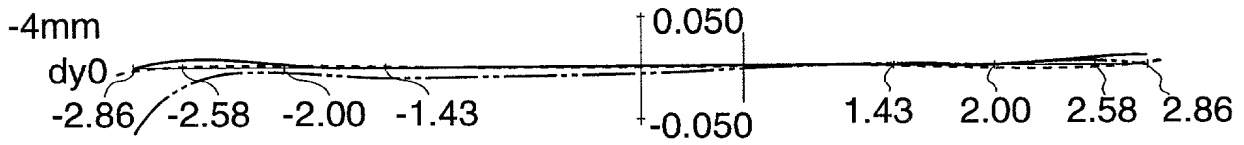


FIG. 6C

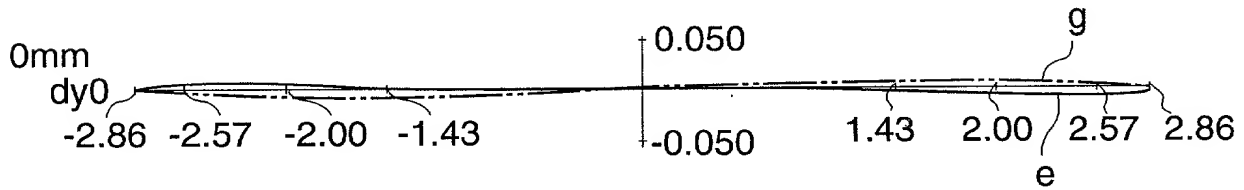


FIG. 7A

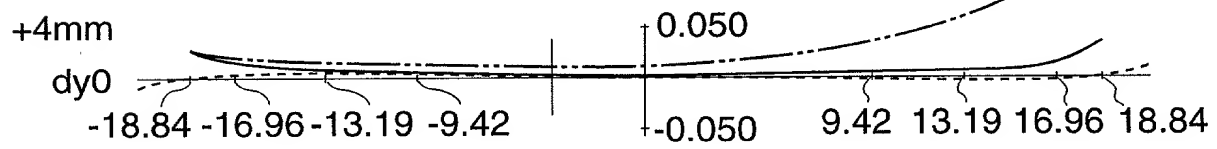


FIG. 7B

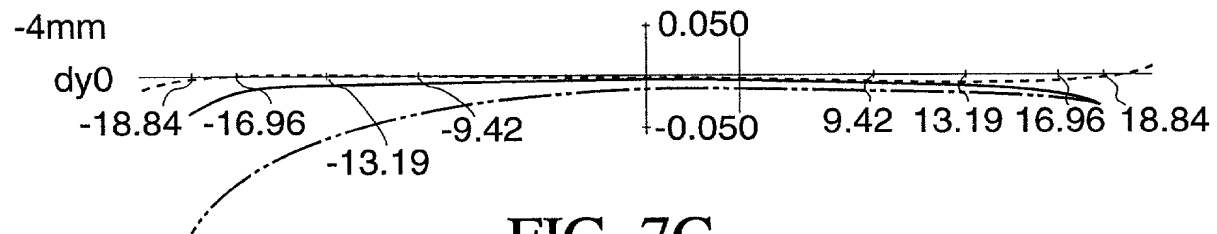


FIG. 7C

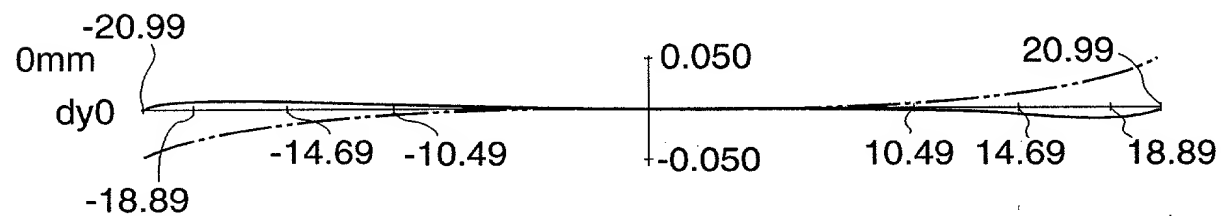


FIG. 8A

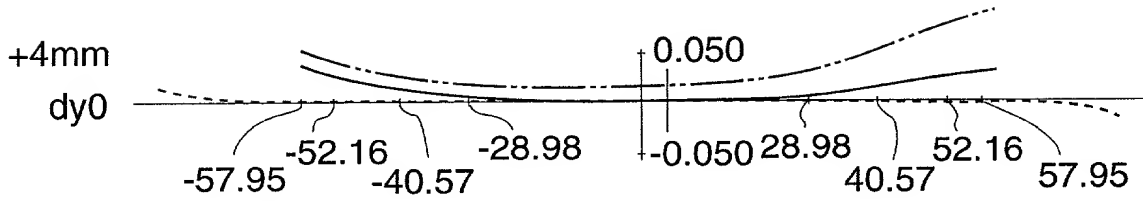


FIG. 8B

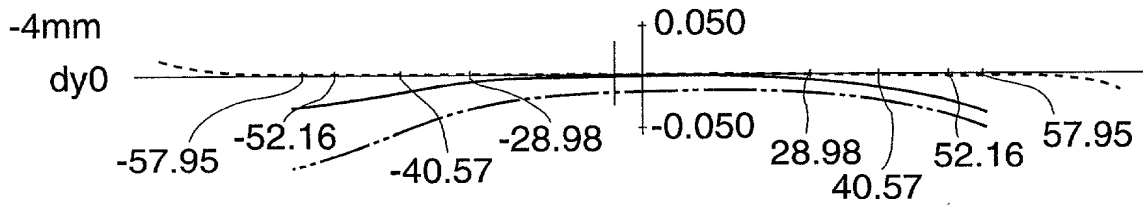


FIG. 8C

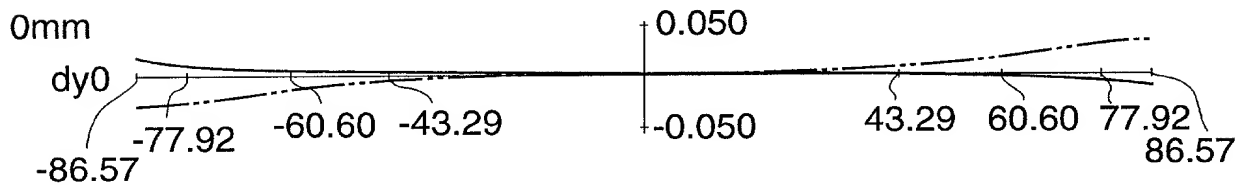


FIG. 9A

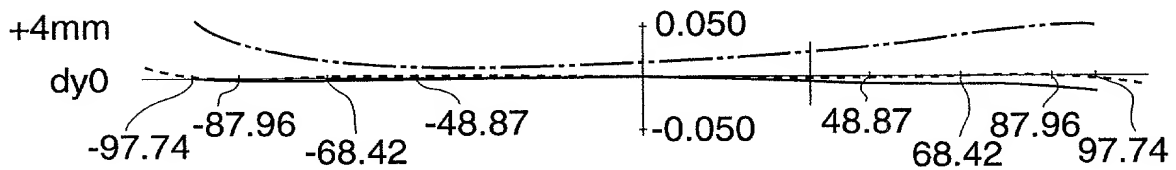


FIG. 9B

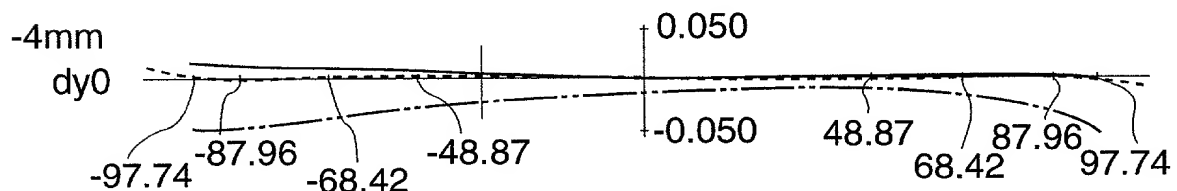


FIG. 9C

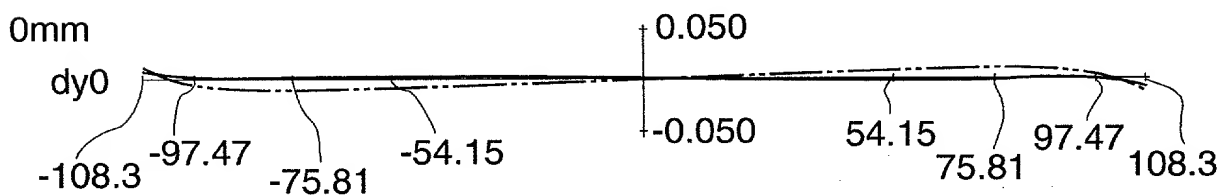




FIG. 10A

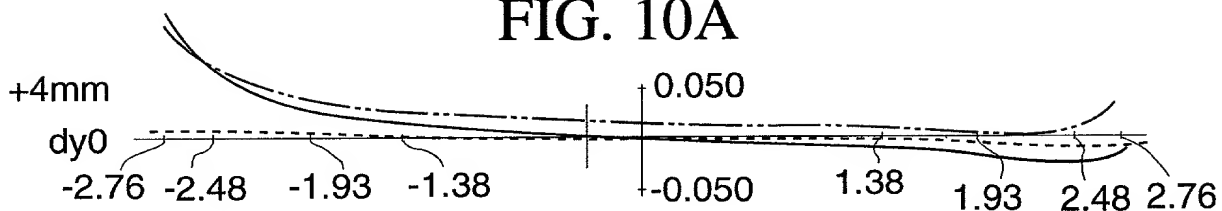


FIG. 10B

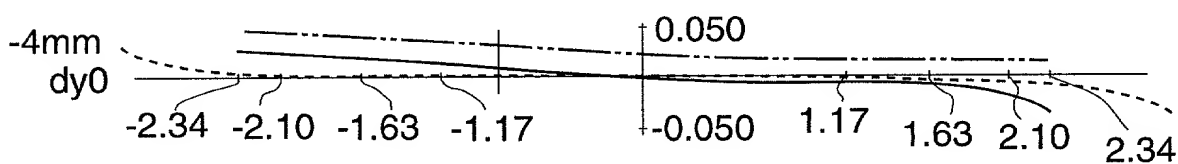


FIG. 10C

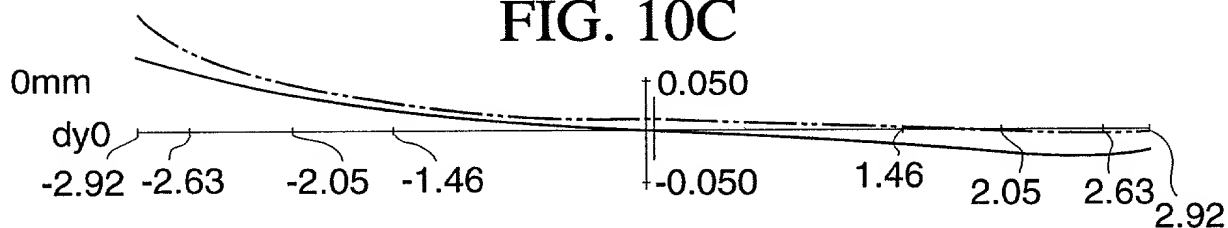


FIG. 11A

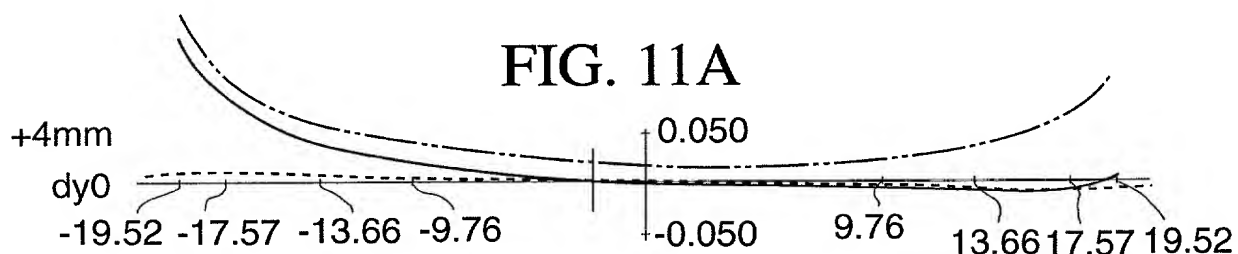


FIG. 11B

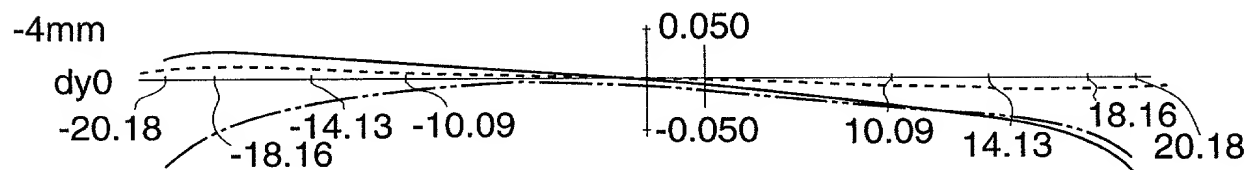
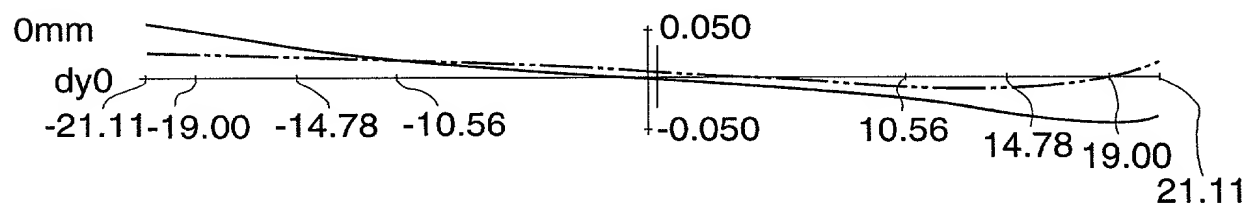


FIG. 11C



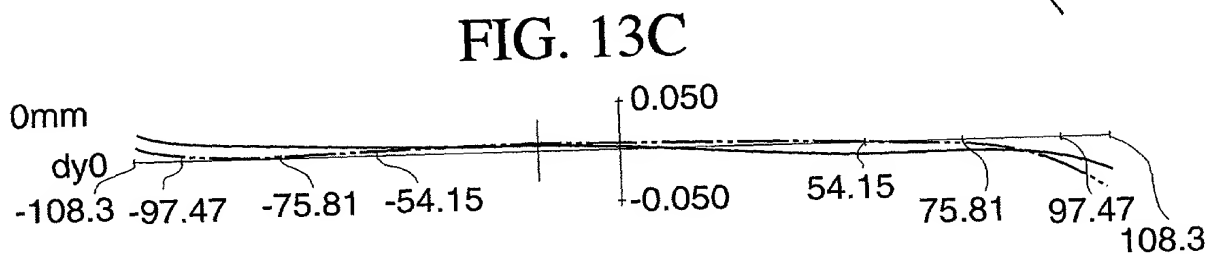
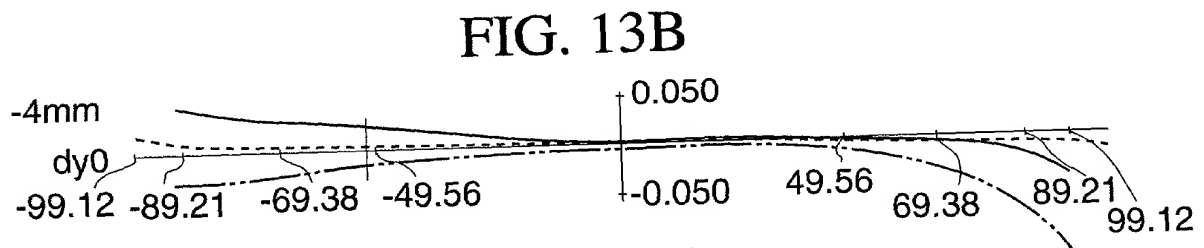
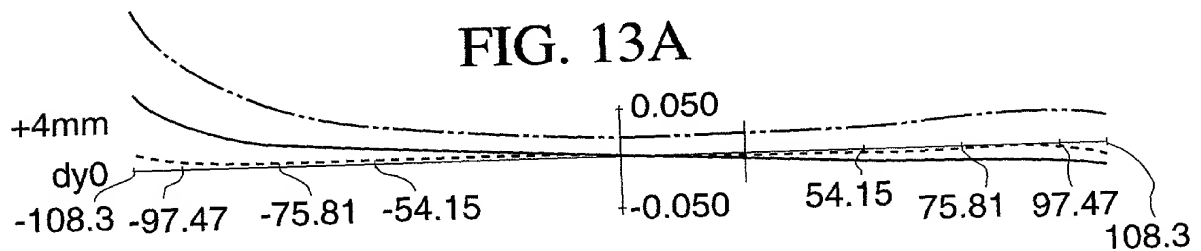
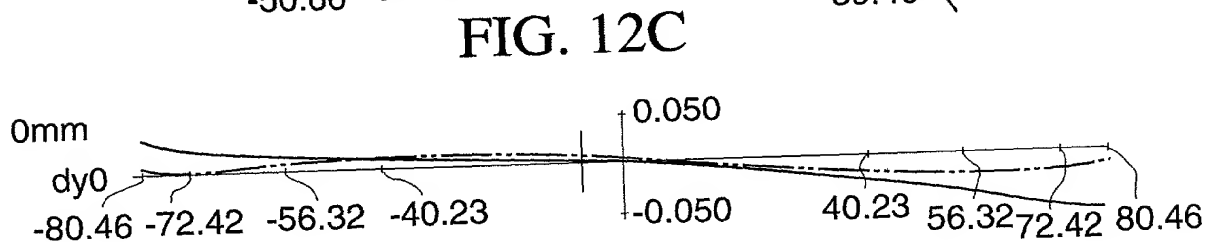
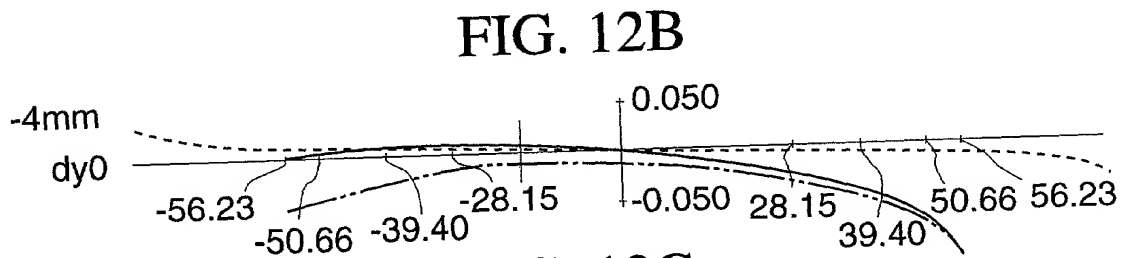
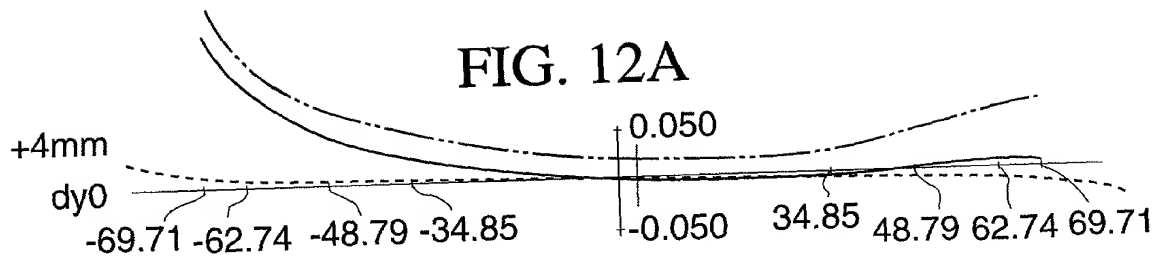
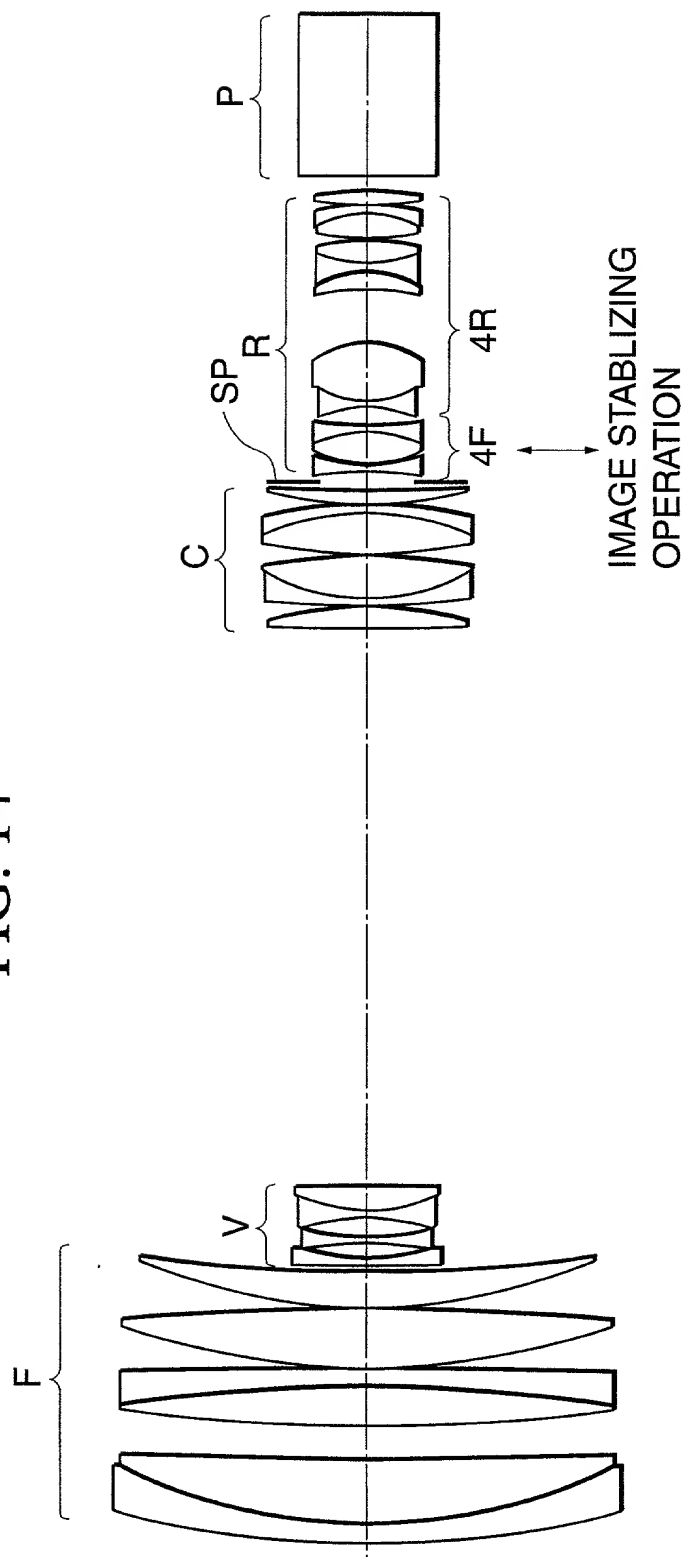


FIG. 14



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FIG.15A FIG.15B FIG. 15C FIG.15D

$F_{no}/1.8$

$\omega=28.8^\circ$

$\omega=28.8^\circ$

$\omega=28.8^\circ$

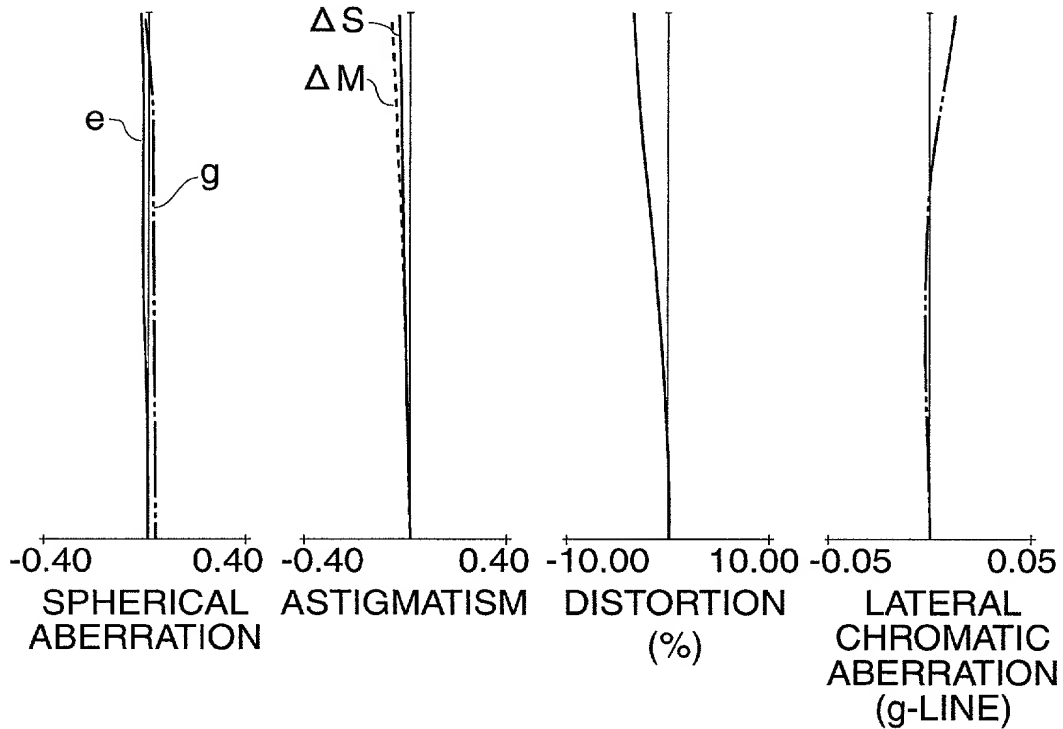


FIG. 16A FIG. 16B FIG. 16C FIG. 16D

$F_{no}/1.8$

$\omega=4.5^\circ$

$\omega=4.5^\circ$

$\omega=4.5^\circ$

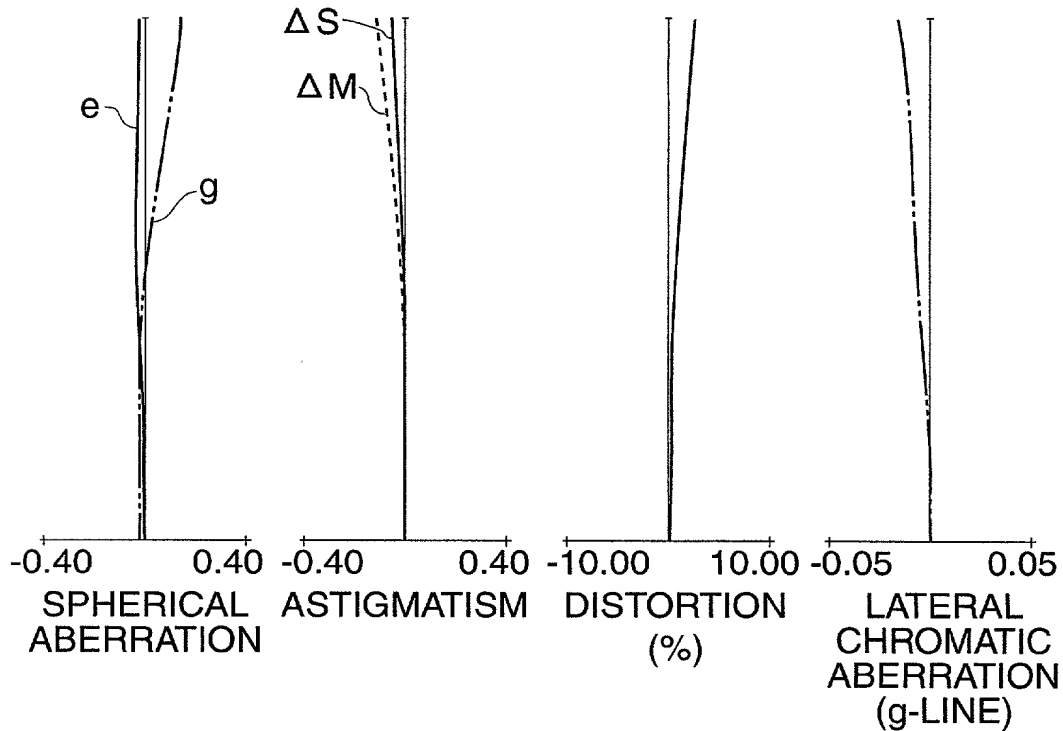




FIG. 19A

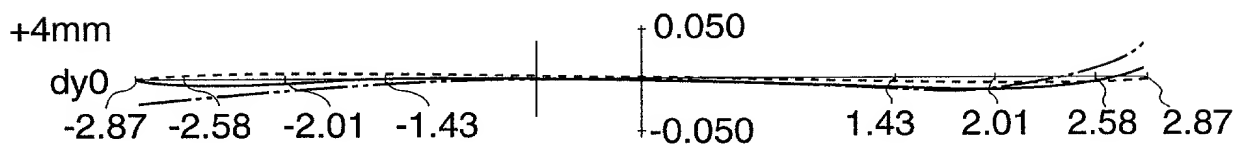


FIG. 19B

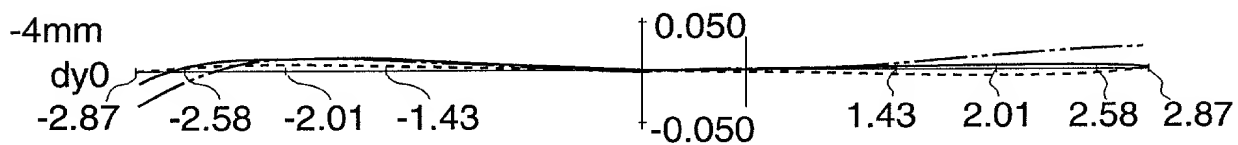


FIG. 19C

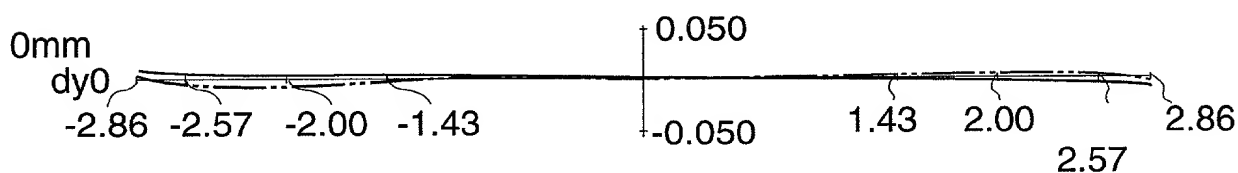


FIG. 20A

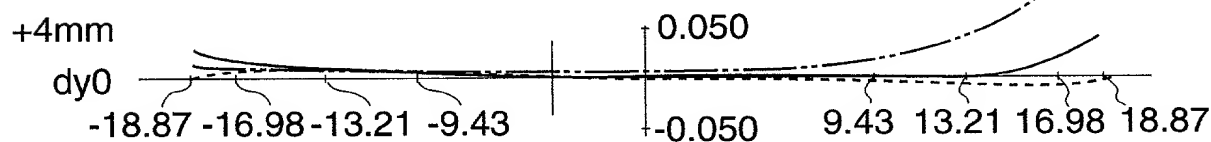


FIG. 20B

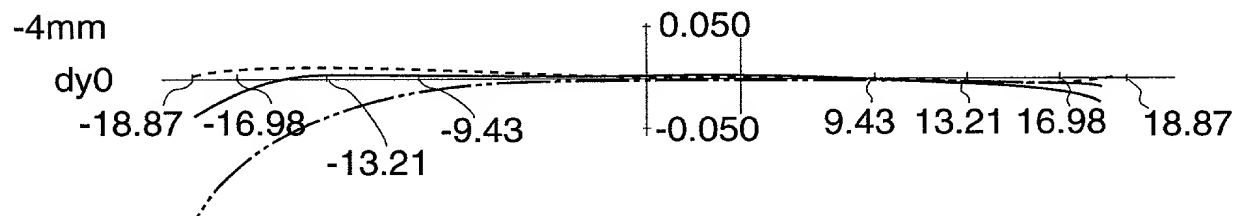
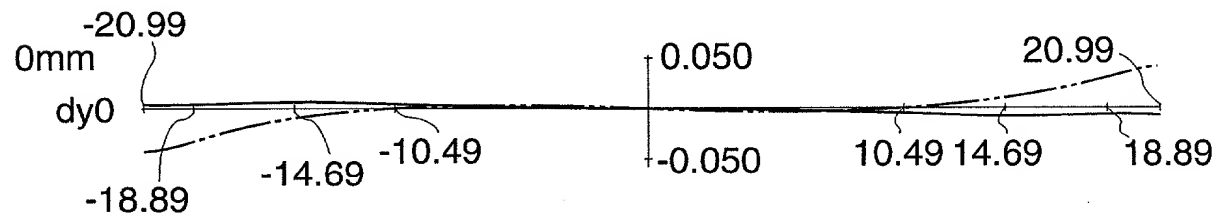


FIG. 20C



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FIG. 21A

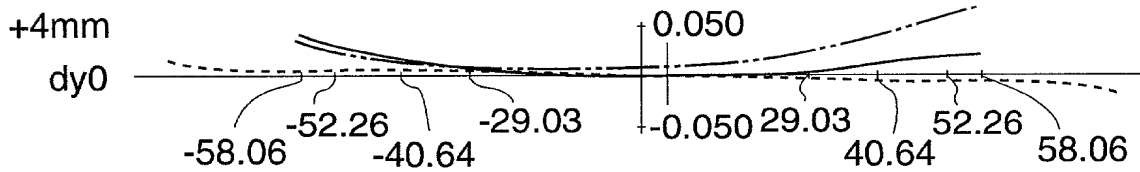


FIG. 21B

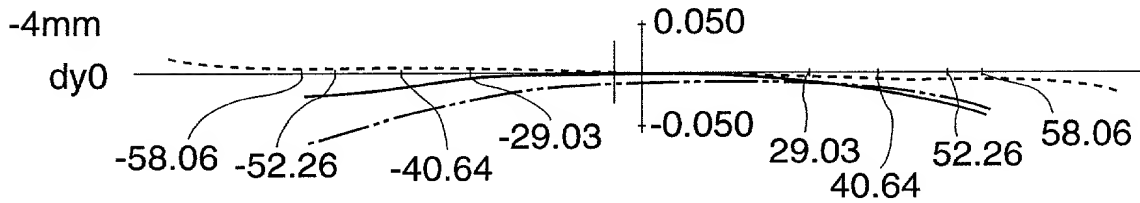


FIG. 21C

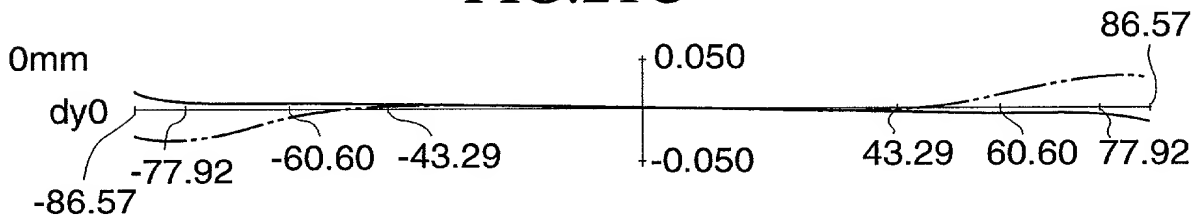


FIG. 22A

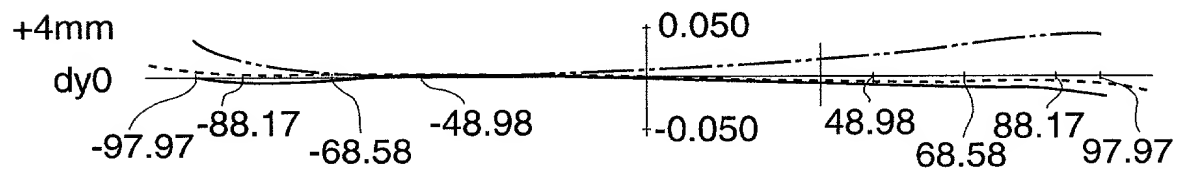


FIG. 22B

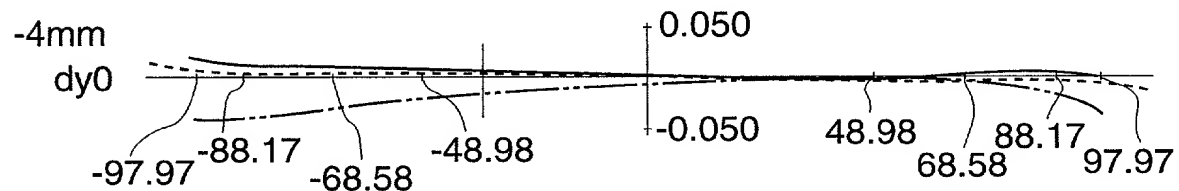
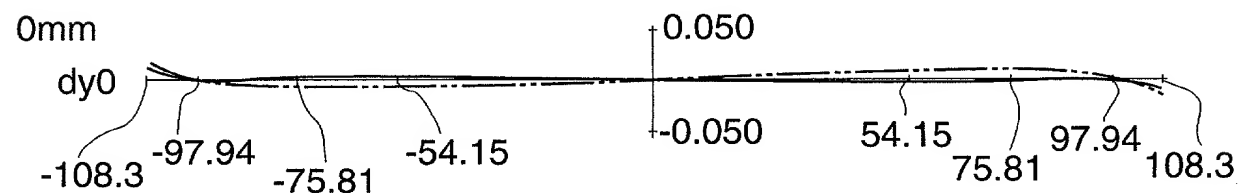


FIG. 22C



009250" 19969360

009260-19969960

FIG. 23A

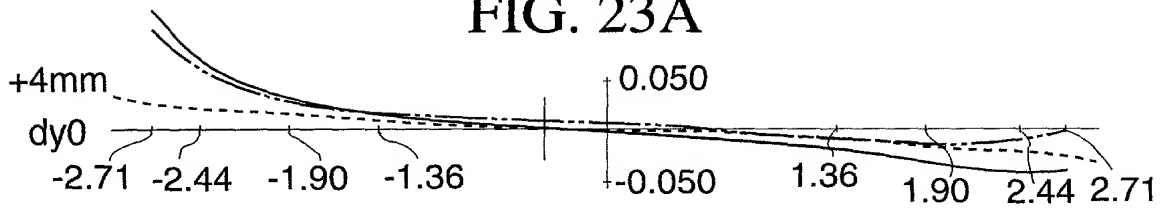


FIG. 23B

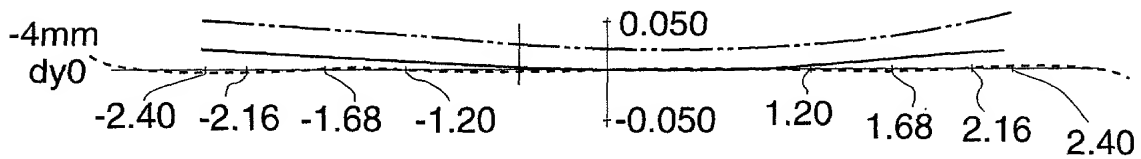


FIG. 23C

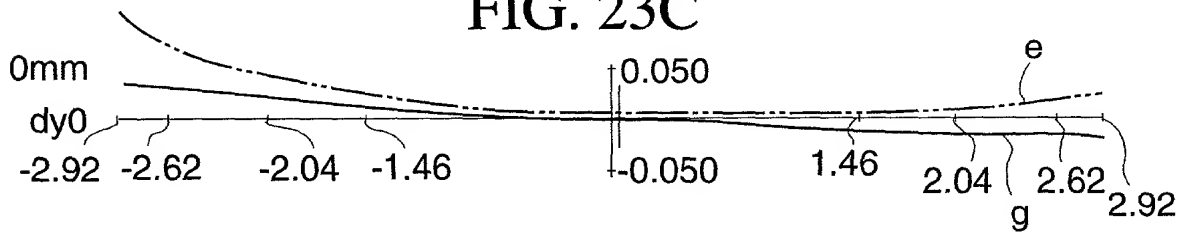


FIG. 24A

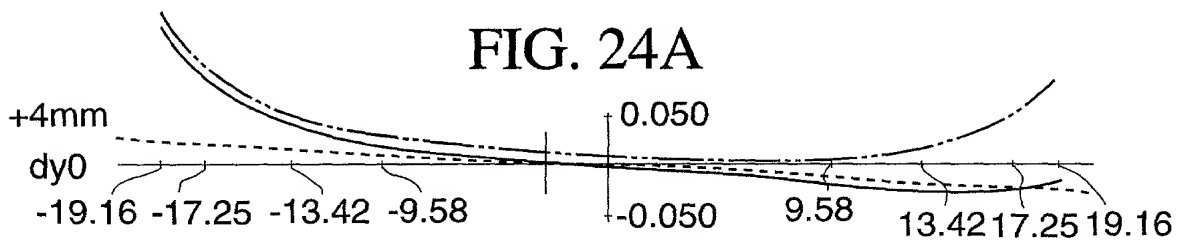


FIG. 24B

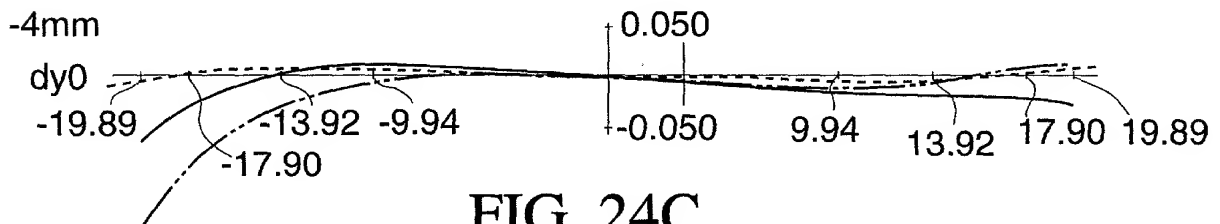


FIG. 24C

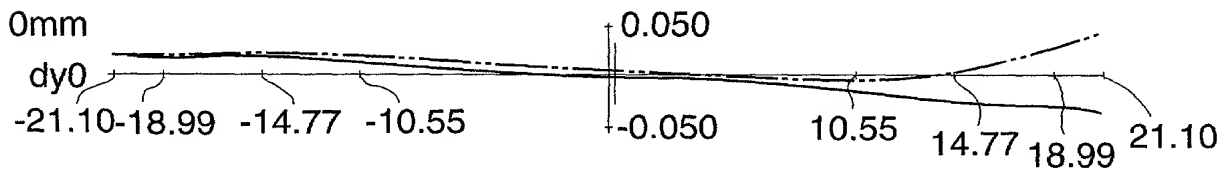




FIG. 25A

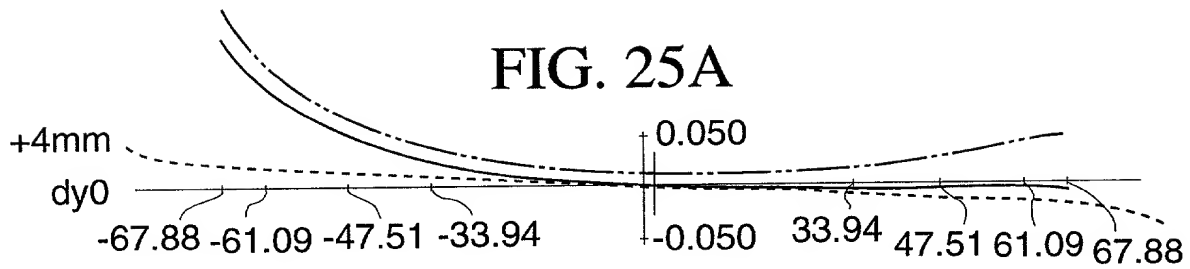


FIG. 25B

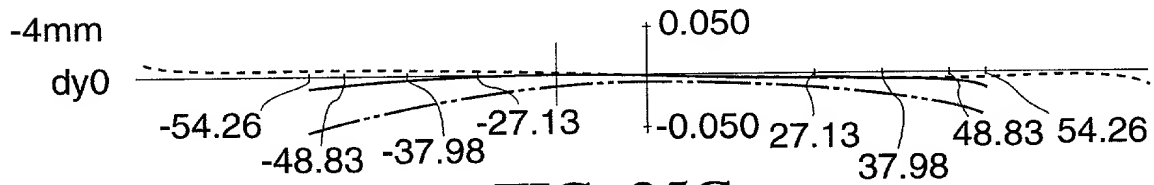


FIG. 25C

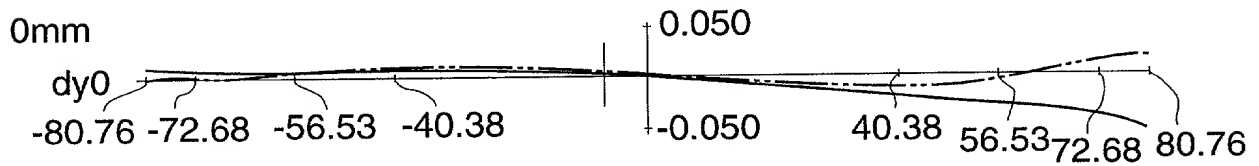


FIG. 26A

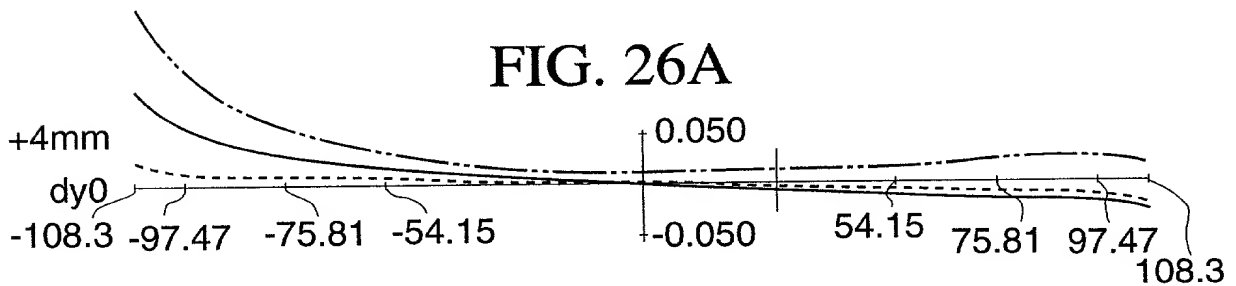


FIG. 26B

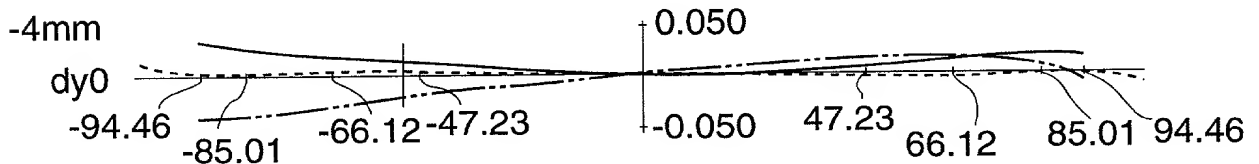
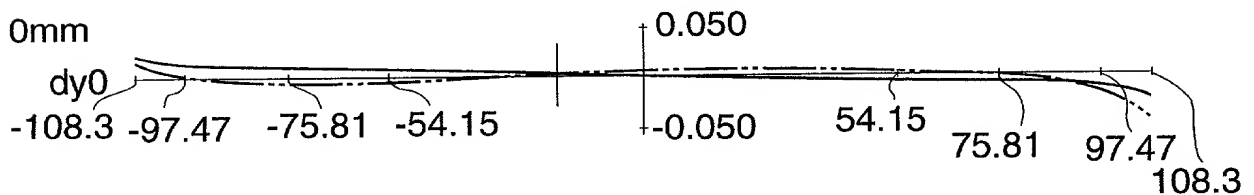


FIG. 26C



003260-19363260

FIG. 27A

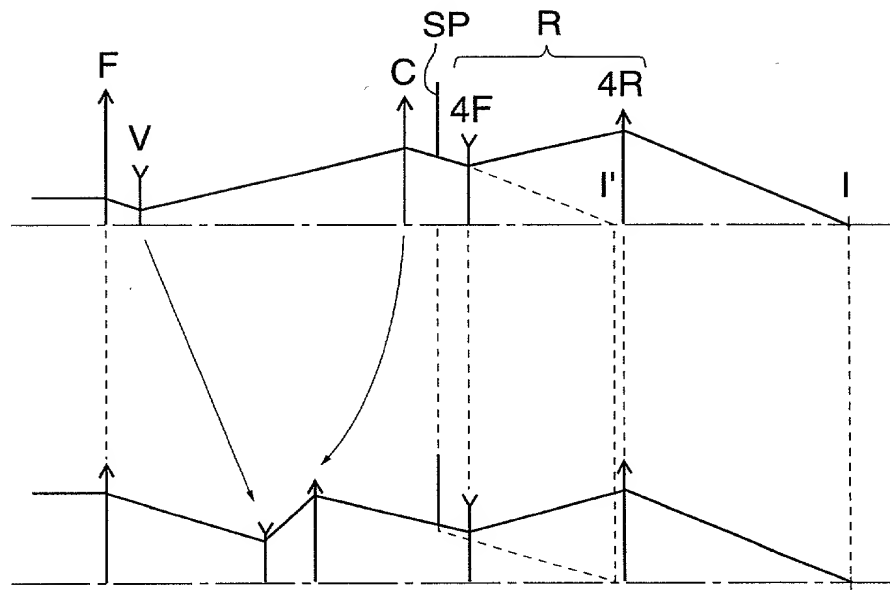


FIG. 27B

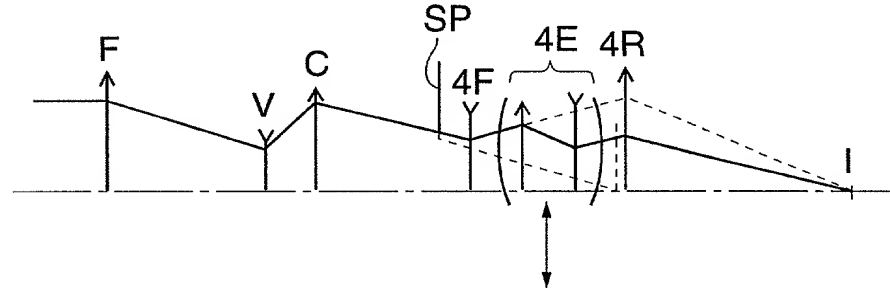


FIG. 28

